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SBIR Topic N96-056 Phase I Final Report: VIRTUAL VERTICAL AIRCRAFT SIGNAL TRAINER FEASABILITY STUDY

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13. ABSTRACT ***(Maximum 200 Words)***

In order to reduce the costs associated with training a Landing Signalman Enlisted (LSE), the Navy has initiated a research and development program to capitalize on current and emerging virtual environment technology. Advances in virtual environments may provide a cost effective solution to the current live helicopter operations method of training, provided technical issues associated with hand and wand signal motion capture and analysis can be solved. This report presents the results of a Phase I SBIR (Topic N96-056) feasibility study to evaluate the potential for a virtual vertical aircraft signal training system development.

The approach included: evaluating and reviewing current, emerging and novel technologies in human motion analysis and virtual environment displays for potential use in this device; collecting and reviewing fleet input, pertinent rules, regulations and policies and potential facility constraints to help determine the optimal design of the device to support fleet requirements and interests. And reviewing current, emerging and novel technologies for creating a cost effective alternative to the present mode of training.

As a result of the feasibility study features of the LSE's operating environment have been identified and found compatible with current and emerging commercial off-the-shelf (COTS) multimedia computer technology. The development of a cost effective complement to current live helicopter LSE pad training sessions based on inexpensive personal computer technology is possible. The widespread use of helicopters by other federal and civilian agencies makes rapid commercialization of this technology extremely likely.

It is recommended that this effort be continued into Phase II with a proof of concept prototype development.

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EXECUTIVE SUMMARY

PROBLEM

In order to reduce the costs associated with training a Landing Signalman Enlisted (LSE), the Navy has initiated a research and development program to capitalize on current and emerging virtual environment technology. Advances in virtual environments may provide a cost effective solution to the current live helicopter operations method of training, provided technical issues associated with hand and wand signal motion capture and analysis can be solved.

OBJECTIVE

Conduct a feasibility study to evaluate the potential for a virtual vertical aircraft signal training system development.

APPROACH

Evaluate and review current, emerging and novel technologies in human motion analysis and virtual environment displays for potential use in this device. Collect and review fleet input, pertinent rules, regulations and policies and potential facility constraints to help determine the optimal design of the device to support fleet requirements and interests. Review current, emerging and novel technologies for creating a cost effective alternative to the present mode of training.

FINDINGS

The features of the LSE's operating environment have been identified and found compatible with current and emerging commercial off-the-shelf (COTS) multimedia computer technology.

CONCLUSIONS

The development of a cost effective complement to current live helicopter LSE pad training sessions based on inexpensive personal computer technology is possible. The widespread use of helicopters by other federal and civilian agencies makes rapid commercialization of this technology extremely likely.

RECOMMENDATIONS

Continue with proof of concept prototype development.

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INTRODUCTION

In order to reduce the costs associated with training a Landing Signalman Enlisted (LSE), the Navy has initiated a research and development program to capitalize on current and emerging virtual environment technology. The purpose of the Phase I effort was to survey human movement analysis, visual, audio and tactile display technology within the virtual environment / virtual reality (VE/VR) arena and determine the feasibility of a cost effective complement to the current training procedures. While sophisticated dynamic simulations are readily available in the high end workstation environment, the thrust of this study was to determine if a training device that accurately replicated the LSE's operational environment could be developed around inexpensive personal computers (PCs) at near workstation quality. The results of this research demonstrate that a personal computer based Virtual Vertical Aircraft Signal Training (VVAST) device is indeed possible.

Characterization of the LSE's duties, responsibilities and working conditions involved the combination of literature reviews, personal interviews and direct observations of live pad training sessions at both east and west coast LSE / Helicopter Control Officer (HCO) schools. The literature included reviews of the LSE Personnel Qualification Standard (PQS), formal training course outlines and several pertinent NATOPS publications. Personal interviews with twelve fleet LSE instructors helped define the educational challenges faced by the VVAST device. The two site visits enabled observations of three live helicopter pad training sessions where student LSEs gained their initial experience signaling to a hovering helicopter. Detailed review of videotape and photographic data recorded during theses sessions identified several biomechanical variations of the standard hand signals described in the Aircraft Signals NATOPS Manual (NAVAIR 00-80T-113). The movement variation must be rapidly and accurately interpreted by the motion capture system in order for the LSE to react with the virtual environment in a timely manner.

Recent advances in personal computer hardware and software have enabled the creation of a high quality interactive virtual environment that presents the LSE trainee with a compelling and challenging training simulation. The VVAST device is intended to complement current training procedures by allowing the LSE instructors to present hazardous or emergency situations to the trainees that are not prudent to demonstrate in a live pad session. The LSE is a critical component in shipboard helicopter operations. A review of twenty two mishap summaries provided by the Naval Safety Center in which an LSE was mentioned in the narrative or listed as a causative factor underscored the importance of an expert LSE. The data represented mishaps involving six different helicopter models (CH-46, CH-53, HH-46, SH-2, SH-3 and SH-60) operating off of several different platform types.

Situational awareness and flight deck management skills are two of the more difficult concepts to develop in an LSE trainee. The LSE is responsible for supervising the flight deck landing area during all helicopter operations. Small procedural omissions or errors have produced mishaps where unsecured equipment staged on the flight deck was blown overboard and lost at sea by the rotor downwash. In other cases, the LSE's failure to maintain a proper lookout doctrine was a causative factor in helicopter collisions with shipboard or pier-side structures. Personnel entering the landing area without the LSE's approval have been severely

injured or killed. While the LSE is monitoring the flight deck area he or she must also monitor the helicopter for any developing hazardous or emergency conditions. These types of situations may begin with something as benign as inappropriate signals from the aircrew or maintenance personnel. The implementation of the VVAST device will enable the LSE instructors to present some of these situations to the trainees without the associated risks to personnel and equipment.

Helicopters are an integral part of the American landscape. They are in widespread use in law enforcement, emergency medical services (EMS), forest and wildland management and firefighting, search and rescue (SAR) and transportation. Air ambulances and offshore oil platform support represent two areas where the helicopter must routinely land in a confined area under less than ideal conditions. Although ground signalmen may be present, there is a substantial variability in both the level of signalman training and experience in helicopter operations. An identical analysis of civil helicopter usage was conducted during the Phase I effort to determine the potential for transfer of this technology to improve helicopter operations safety in the aforementioned market segments. Personal interviews with representatives of the United States Departments of the Interior (Office of Aircraft Services) and Agriculture (Forest Service) identified many similar training features and educational challenges. The results of additional interviews conducted with pilots from a state police agency's airborne rescue division supported the universal applicability of the VVAST device as a training system to improve helicopter operations safety.

A review of two hundred and thirty five helicopter mishap summaries covering the years 1983 to 1996 provided by the National Transportation Safety Board yielded several common themes observed in the military mishap data. Eighty three mishaps involved EMS or air ambulance helicopters with more than half occurring at or near remote accident scenes. While many police, fire and EMS departments have existing procedures requiring the use of a ground signalman, the mishap summaries were strongly suggestive of the need for a consistent level of training in landing area management and situational awareness. The most common mishap involved flight into electrical power lines near the landing zone that were not seen by or reported to the pilot. Main and /or tail rotor blade strikes with nearby fencing, lights, poles or buildings were also prevalent with at least four mishaps resulting directly from the unexpected intrusion of unauthorized personnel or emergency vehicles in the path of the departing helicopter. The operating area faced by the light EMS helicopters varies widely in terrain elevation and character. Winds have played a significant role in several mishaps since these helicopters may be closer to the edge of their performance envelope on any given day than the more powerful military helicopters. The remaining mishaps were divided into oil platform support, logging, law enforcement and other categories. While the latter category had few mishaps in which a trained ground signalman may have prevented or minimized the mishap, all other categories did present situations where an extra observer controlling the landing area would have minimized the accident potential.

Some initial steps have been taken by various agencies to promote quality signalman training yet nothing is presently available or even discussed within the trade literature that offers the same potential for improving helicopter ground operations safety as the proposed Virtual Vertical Aircraft Signal Trainer. The continuing improvements in widely available personal computers have made it possible to offer a high quality virtual simulation of an extremely dynamic situation on a platform already used by most military and civilian agencies.

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FEATURE IDENTIFICATION

The identification of the tangible and intangible features necessary to create a training device that reproduces the LSE's environment with fidelity was substantially advanced by the visits to the two LSE schools. The visits were arranged by Dr. Tom Franz and included both personnel interviews and observations of LSE class day and night helicopter flight operations. The site visit to Helicopter Combat Support Squadron THREE (HELSUPPRON THREE) at NAS North Island occurred on August 14, 1996. An additional site visit to the Atlantic Fleet Helicopter Operations School at Helicopter Combat Support Squadron EIGHT (HELSUPPRON EIGHT) at NAS Norfolk occurred on September 10-11, 1996. We were fortunate to have the opportunity to interview two CH-46 Sea Knight pilots and ten staff LSE instructors during the site visits. The discussions centered on eliciting their views of the ideal LSE's performance and their own personal experiences. We were particularly interested in identifying the factors used by the LSE in determining what the next step in the evolution was.

The interviews followed surveys developed early in the project and were very successful in eliciting many details of the LSE's work that are not available from the literature. This discussion is divided into five parts: (a) LSE formal training, (b) Desirable LSE characteristics and behaviors; (c) Situational awareness requirements, (d) General experience features and (e) Hazardous and emergency situations. When all were in agreement, a summary of the comments is provided. When differences of opinion and/or experience were present, all viewpoints are included in the discussion.

(a) LSE formal training

There are two formally designated Landing Signalman Enlisted schools located at NAS North Island, CA and NAS Norfolk, VA, serving the Pacific and Atlantic Fleets respectively. HELSUPPRON THREE at NAS North Island is the Model Manager. The Atlantic Fleet Helicopter Operations School is a part of Helicopter Support Squadron EIGHT at NAS Norfolk. Each command offers a five day training program that combines didactic and practical instruction in the LSE's duties and responsibilities. The course numbers are E-600-0506 and D-600-0506 for the HELSUPPRON THREE and EIGHT schools respectively. Each class consists of twenty to twenty four students from a variety of commands and agencies. Attendees are mostly from military commands although civilians from other federal agencies may attend the training. A typical class profile was obtained during the first site visit. LSE Class number 96210 was approaching their first live helicopter training sessions on the day of our site visit to HELSUPPRON THREE. The class was composed of twenty students of various rates, pay grades and experience levels. Some of the students had observed fleet LSE signals while others were at their first duty station and had no fleet experience. The student population was a mixture of aviation and non-aviation rates as shown in Table 1. The non-aviation rates were BM3s and BMSNs.

Table 1. LSE Class 96210 Composition

Pay grade	Rating		Command Type		
	Air	Non-Air	Squadron	LHA/LPD	Air Capable Ship
E-6	1			1	
E-5	2		2		
E-4	4	4	1	3	4
E-3	4	2	2	2	2
E-2	3			3	
Subtotals	14	6	5	9	6

In addition to the twenty active duty students, three civilian federal employees were part of LSE Class 96173 at HELSUPPRON EIGHT. Two were part of the Military Sealift Command and one was from the U.S. Marine Management Agency.

Student Progress and Success Rate

A universal comment from instructors at both schools was that the aviation rates seem to learn the required material faster since they have already been exposed to the terminology and concepts. LT Marshall (HC-3) indicated that the training program has had few, if any, student failures in recent history. ADC (AW/NAC) Silvestre (HC-8) also stated that there have been no failures in the training. The major source of student difficulty is in performing the proper hand signals. When a student has significant difficulty with the hand signals, an instructor will work with them on an individual basis until an acceptable level of performance has been achieved. A written examination is given to each student at the end of the training. If a student fails the test, an instructor will work one on one with the trainee to ensure that the concepts are well understood. There was not fleet feedback regarding student performance received by either school.

Personnel Qualification Standard

The optimal place to begin the analysis of what features are desired in the VVAST device is to review the LSE Personnel Qualification Standard (PQS) for what topics are covered in the LSE school. The Navy's Personnel Qualification Standard system provides an excellent means of ensuring a continuous quality control by having the PQS reflect the general but not the specific requirements of a particular qualification. Personnel qualified to sign off the various watch stations typically come from the senior petty officer ranks and must already be qualified in the task they are signing off in the trainee's PQS book. In this means, the Commanding Officer has a means in place for ensuring that the trainee has met all relevant Naval Air Training and Operating Procedures Standardization (NATOPS) and local command procedures through a personal review before designating an individual as watch station qualified. Each command may have slightly different policies or factors (i.e. a squadron's helicopter) that are relevant to the PQS but may not reflect the specifics pertinent to another command. Therefore, the LSE school provides training in a portion of the required fundamentals and watch stations. It is then up to

the trainee to complete the remainder of the appropriate watch stations.

The LSE PQS, NAVEDTRA 43436-A, is the most current version having been released in November, 1995. The program is composed of a fundamental section (100 series section numbers) and four separate but related watch stations (300 series section numbers). The four possible qualifications available to the LSE trainee through this PQS are:

301 CV/CVN Deployable Squadrons - Landing Signalman Enlisted (LSE)
302 LHA/LHD/LPH/LPD/MCS Deployable Squadrons - Landing Signalman Enlisted (LSE)
303 Air Capable Ships - Deployable Squadrons - Landing Signalman Enlisted (LSE)
304 Night Vision Goggles (NVG) Operator.

The first three have several common areas that include most of the fundamental requirements that are taught didactically. While several subject areas are common to watch stations 301, 302 and 303, there are some potential areas of training where the VVAST device could enhance the program by enabling the LSE trainee to experience situations that are not practical to duplicate in live operations for safety, time or equipment considerations. As Phase I of this effort is the feasibility study, these features are identified for future development in Phase II. Table 2 lists the common subject areas that are addressed in the LSE school program.

Table 2. Common subject areas included in the LSE School curriculum.

Subject	Watch station 301 section number	Watch station 302 section number	Watch station 303 section number
Conduct Night VERTREP Operations	301.2.7	302.2.8	303.2.9
Incorrect Hand Signals	301.4.5	302.4.5	303.4.6
Engine/APU/APP Fire***	301.5.2	302.5.2	303.5.2
Landing Gear Malfunction***	301.5.4	302.5.4	303.5.4
Hung Droop Stops***	301.5.8	302.5.8	303.5.8
Hung MAD/ dipping sonar***	301.5.10	302.5.10	303.5.10
Hung Antenna (down)***	301.5.11	302.5.11	303.5.11
Thermal Runaway*** (battery)	301.5.12	302.5.12	303.5.12
Ground Resonance***	301.5.13	302.5.13	303.5.13
Lost Communications/ Electrical Failure***	301.5.14	302.5.14	303.5.14

Subject	Watch station 301 section number	Watch station 302 section number	Watch station 303 section number
Tie Downs not properly installed prior to rotor engagement***	301.4.2 *	302.4.2	303.4.2
Tie downs not removed prior to launch***	301.4.3 *	302.4.3	303.4.4
Rotor Brake Failure***	301.5.7 *	302.5.7	303.5.7 *
Direct Personnel/cargo hoisting operations	**	**	303.2.10
FOD producing material present.	**	**	303.4.8
Helicopter In-Flight Refueling (HIFR) Emergency Breakaway	**	**	304.5.15

Note: Items with an asterisk (*) were not listed on the letter of completion but appeared to be identical areas in the PQS. Items marked with two asterisks (**) have no equivalent standard in this watch station. Items marked with three asterisks (***) represent hazardous or emergency procedures that are only discussed in class due to safety limitations in demonstrating this during the live helicopter training sessions.

There are at least three other common subject areas that have significant potential for inclusion into the production device and would enhance the training potential. Each of these areas carries significant risks to personnel and aircraft that eliminate the possibility of presenting this situation during the field training sessions. Blade Strike (PQS 301.5.9; 302.5.9 and 303.5.9), Fouled VERTREP Load (301.4.6, 302.4.6 and 303.4.7) and Landing Gear Fouled by VERTREP Load (301.5.15, 302.5.15 and 303.5.17) are impractical to perform even a single demonstration in live operations but may easily be incorporated into the VVAST device's capabilities.

Live Helicopter Pad Training Sessions

A total of three pad sessions are offered to the students at either LSE school. Each segment is approximately two hours long and enables the trainee to gain experience signaling a helicopter. The pilots are briefed that this is a training evolution and make a good effort towards following the LSE's signals. The operation is conducted at Outlying Landing Field Imperial Beach, CA, on the West coast and on base at NAS Norfolk. OLF Imperial Beach is about ten miles south of North Island and some allowances for travel time must be built into the training period. The CH-46 fuel load allows about an hour of pad work in this type of training. Larger classes make the task of getting all trainees signaling experience a daunting one. A larger class may not be able to complete the pad session with just one helicopter. The proximity of the training area to the flight line at NAS Norfolk eliminates the travel time limitations. Both locations are subject to helicopter availability and weather. A simulated landing area is painted on the landing pad for both pilot and LSE orientation.

The first pad session is a day time launch and recovery practice to build the student's confidence level and get exposure to the noise and wind levels. In this session, the students practice the basic handling signals to place the helicopter on the proper spot. These include the Land Here, Move Forward, Move Back, Move Left, Pedal Turn Left, Pedal Turn Right, Move Right, Move Up, Move Down, Land and Wave Off signals. Depending on the instructor's desires and pilot cooperation, the Trainee may get to use most, if not all, of the basic signals over an approximate two minute contact exposure time. The instructor may wish to demonstrate how the helicopter can move in response to the LSE's signals and do the demonstration himself or have one or more students perform it. While several helicopter models (SH-2, SH-3, CH-46 or SH-60) may be used, the CH-46 was used for the session we observed as the originally scheduled SH-60 was unavailable.

The second pad training is the introduction to Vertical Replenishment (VERTREP) and uses the CH-46 helicopter. Several concrete blocks (HC-3) or a four foot concrete cube (HC-8) is used as the simulated pallet load. This may be a day or night session depending on helicopter availability and scheduling. Since the helicopter doesn't typically land during the VERTREP evolutions, the students use the Hook Up Load and Release Load signals in place of the Land signal. The other ten basic helicopter signals are used normally during this session. The students gain actual experience in both the LSE and Hook Up Man positions. The latter position attaches the replenishment pendant from the load to the helicopter while the aircraft is in a hover signaled by the LSE. Once the load is attached and the Hook Up man has left the immediate area, the LSE signals for the helicopter to move up and lift the load.

The LSE's signals are advisory as there is a prescribed voice communication sequence taking place between the pilot and the aircrewman in the helicopter that is described in the CH-46 NATOPS Flight Manual. Therefore, there may be a slight discrepancy between the movement of the helicopter and the LSE's signals with the aircrewman's voice commands taking priority during the training sessions.

Interviews with both LSE instructors and pilots indicated that a sort of "rhythm" develops during a VERTREP operation. The pilots commented that they have a tendency to listen to the aircrewman more than watch the LSE since the aircrewman is also in the helicopter. Several

LSE instructors commented that the most difficult times they had experienced as an LSE were when the pilot did not appear to be responding to their signals. The second pad sessions we observed demonstrated this minor breakdown in communication as the pendant was released from the helicopter before the LSE signaled "Release Load" on several segments. The student contact time in the LSE position is less than the first pad session as the helicopter does not land. The pick up load segments last between forty and sixty seconds from initial approach to departure. The drop load segments take slightly less time. Each student gets to signal one drop and one pick up segment before moving to the Hook Up Man position.

The training sessions we observed went well but the quality of signals seemed to decrease as the speed of the evolution appeared to increase. This wasn't necessarily apparent during the sessions but has been suggested in the review of the videotapes. There are several instances where no hover signal is given after the move down signal in either the pick up or drop load segments although the LSE was continuously visible in the video. In other segments, no clearing turn was issued before the pilot was given the Take Off signal. It appeared that the students may have been trying to keep up with the fast pace of the operation and not necessarily control the evolution by proper signaling. The instructors would include such errors in a general debrief at the end of the pad session. Individual feedback is provided as necessary.

At the LSE school at HELSUPPRON THREE, the helicopter makes a quick trip around a traffic pattern between drop and pick up segments. The LSE program at HELSUPPRON EIGHT uses a modified pattern that reduces the number of trips around the pattern by having the LSE reposition the hovering helicopter to allow the Hook Up Man and instructor to safely approach the load. Once the Hook Up Man is ready, the LSE will signal the helicopter back into the pick up position. After the load is attached, the helicopter will depart normally. The difference in the patterns may be due in part to geographical restrictions. The training pad at OLF Imperial Beach lies as the southernmost pad in a row of six landing pads arranged north to south. The other pads are also in continuous usage and the hover mode repositioning would present a safety hazard to the other aircraft. The only option would to be move the hovering helicopter to the south where it would hover over unprepared dirt while the Hook Up Man and instructor approach the load. Extended operations in a confined area over loose sand and dirt would raise a safety of flight visibility issue. The training pad at NAS Norfolk is located along the sea wall away from the flight line. The difference between patterns does not appear to significantly affect the LSE training in this evolution.

There are differences in the third pad training session between HELSUPPRON THREE and HELSUPPRON EIGHT. The last pad session at Imperial Beach is an introduction to hoisting and helicopter in-flight refueling (HIFR). This evolution usually requires an SH-2 or SH-60 and the HIFR apparatus at OLF Imperial Beach. The CH-46 does not participate in the hoisting operations due to a NATOPS limitation. This variation is due in part to the lack of a HIFR apparatus at the Norfolk training pad. Therefore, the third pad session at HELSUPPRON EIGHT focuses on developing the LSE's comfort and assertiveness by introducing a limited number of hazardous situations that require the LSE to take immediate action. These situations do not endanger the helicopter or ground personnel but represent common occurrences that would result in a mishap if not rectified immediately. Examples include loose gear in the landing area, people walking through the landing area as the helicopter approaches and an approach

flown too high and too fast. As the LSE is the primary observer of flight deck safety, this does provide some exposure to commonly occurring situations.

The students observe the training session from a nearby position (75 to 100 feet abeam or offset from the pad area). The students are able to watch each other's signals in the LSE trainee's position and the helicopter's responses. In addition to gaining a true appreciation for the amount of noise and rotor down wash buffet, this situation has the additional benefit of having the students in the back of the line practicing and refining their signals before they stepped up to the trainee's position.

Although they have taught classes of 25 students, none of the instructors were particularly comfortable with large classes. It is difficult to get the entire class through the training session if the assigned helicopter is late or absent. Inclement weather can also reduce the amount of training time available to the students. These are substantial arguments in favor of a training device like the proposed VVAST simulator. It would be foolhardy to state that a simulator can replace all pad sessions. However, it is conceivable that such a device could replace a portion of the pad sessions and allow the trainee to more firmly grasp the concepts and responsibilities of the LSE's work.

(b) Desirable LSE characteristics and behaviors.

The goal of the survey questions was to develop a clear understanding of what the ideal LSE is, if one were to exist. What qualities, mannerisms, habit patterns do the most successful candidates possess that those trainees who may not fare as well do not? We hoped to identify what characteristics the instructors feel can be taught to the students as well as those inherent in a good LSE. The consistent comment in all interviews was the efficiency of the LSE. While this was used mainly to describe the quality of the hand signals, the term was extended to include the scan pattern, situational awareness and flight deck management.

Signal Performance

Forty one helicopter handling signals are described in the Aircraft Signals NATOPS Manual (NAVAIR 00-80T-113). Thirty five helicopter signals are given strictly by the LSE. The signals are individually discussed in the Motion Analysis section. Each signal should be crisp and given at an even pace that clearly identifies the meaning.

The speed of the hand signals varies across individuals and even within the same individual over time. Some of this variation is deliberate as the LSE tries to communicate "I want you to take this action faster (slower)" to the pilot nonverbally. The LSE may have received direction from the Air Boss or Helicopter Control Officer to change the tempo of the evolution. There may also be factors that the pilot is unaware of that cause the LSE to modify the signal speed. Some variation in the standard signal speed results from the individual's plan to sharpen the movement. This refers to the movement strategy planned by the LSE to make his or her hand signals more distinct to the pilots and is another subtle indicator of the LSE's self confidence level. The directional signals (i.e. Move Left/ Right/ Up/ Down/ Forward/ Back and

Pedal Turn (Move Tail) Left / Right) are where most of this variation takes place. In the Move Left signal for example, the LSE may apply several movement strategies to produce acceptable movement. The left arm (assume rotation about the shoulder for the moment) may be continuously moved from the horizontal to the vertical and back to the starting position in one movement strategy. A second method of producing an acceptable signal is to move the left arm from the horizontal to the vertical, pausing briefly, returning to the starting position, pausing for a slightly longer time then resuming the upward movement.

These are two of the many possible movement strategies that can produce an acceptable movement. They are also good examples of what personal styles the LSE can use to produce appropriate good quality signals that nonverbally set the tone for the pilot-LSE interaction and the evolution tempo. The pilots commented that each LSE develops their own personal style and they may be identified from a distance by this pattern. Once the LSE's signaling habits become familiar, the pilots are quick to detect any change in the nonverbal communication and may use this as a decision making factor. Each pilot stated that if they have an emergency situation in the helicopter, the best thing the LSE can do for them is not get caught up in the situation and keep their signaling patterns consistent with previous behavior. Deviations from accepted normal signaling habits are more of a distraction.

The critical point to distill from the signal speed discussion is that multiple strategies are used to produce appropriate, high quality hand signals of the same movement. Therefore, the motion analysis system must be robust enough to allow a range of acceptable movements yet discern the inappropriate movements.

We wanted to determine if there was a point in the signaling process where the LSE may modify the magnitude or frequency of the arm movements and if there was such a point, what were the indications. This information is considered important to the movement pattern analysis module development. The speed of the signals should not change especially in a training scenario. The movements of the signals should not be rushed or exaggerated but smooth, crisp and efficient. This point was emphatically stated by all of the instructors who also indicated that this is one of the more difficult parts of the training program. Rushed or exaggerated signals are used by both pilots and instructors as a visual indicator that the LSE is losing or has lost situational awareness. The field sessions were an outstanding venue to observe the significant magnitude and frequency variations of stereotyped movements among the trainees.

The hand signals are used to communicate several important bits of information to the pilot. The first and most obvious information that is transmitted is "Take this action now." The only signals requiring mandatory compliance by the pilot are the Wave Off and Hold signals. All other signals are advisory according to NATOPS. Therefore, the pilot who has the final authority on safety of flight may choose to disregard a hand signal he or she feels is unclear, inappropriate or would result in an unsafe condition. Several subtle nonverbal statements are also contained in each hand signal in terms of the pace, LSE's self confidence and confidence in the pilot, level of professionalism and quality of flight deck management. An attentive and efficient LSE is ideal and with proper training and exposure, this can be developed.

The pace of different signals is an important indicator of the LSE's level of situational

awareness and stress level. The pace refers to the tempo of how often the signals change (i.e. Move Up to a Hover to a Clearing Turn to a Take Off). If the signals are unevenly paced, the pilots tend to have less trust in the signals. This may tend to exacerbate the situation somewhat if the LSE is already behind the operational pace of the launch or recovery. If the signals are rushed, the pilots stated they will take their time in responding to the LSE's signals no matter how urgent the signals are. This philosophy is appropriate to avoid being rushed into a mishap situation.

Hesitant or indistinct signals suggest that the LSE is not sure of what they are doing or what is taking place around them. The level of self confidence is directly related to the hand signal quality. The pilots commented that if the LSE appears to be hesitant or confused, they will tend to ignore him and land on their own. The demonstration of self confidence by the LSE through crisp, accurate and timely hand signals cannot be understated. Pilots will look for this quality before deciding how much weight to put in the LSE's signals. Flight deck personnel will pay more attention to the directions of a confident LSE thus increasing the safety margin.

The proper hand signals are described in NAVAIR 00-80T-113 and ideally are the only ones the LSE should be using. While the manual may present one version, there are some minor differences in the interpretation of how some signals should be performed. The differences may result from different understandings of the proper form, a variation based on personal preference or popular viewpoints. The Move Left /Right signals have a different interpretation among instructors. The major difference is in which joint (elbow or shoulder) is flexed on the arm that is moving. The Aircraft Signals NATOPS Manual describes the signal as one arm held horizontally while the other is swung over the head in the direction of desired movement. Some instructors teach the movement as rotating the extended moving arm about the shoulder while others taught the movement as keeping the moving arm horizontal and bending at the elbow in the desired direction of movement. The same differences can be stated for the Pedal Turn or Move Tail Left/ Right signals.

All instructors commented on the difficulty of teaching students with some fleet experience not to use unauthorized "fleet" signals. These may be personal flourishes thrown in

such as a salute following a Take Off signal or a wrist loop to emphasize a hover signal. There are a number of small variations that appear to be relaxed versions of the NATOPS signals. Some were evident on the pad session videotapes and may be described as using wrist movements and small elbow movements to replace proper whole arm movements in the directional signals (i.e. Move Left). While some informal peer pressure may exist to use those signals as a sign of being a "fleet sailor," the smaller magnitude movements are far more difficult for the pilot to discern from a distance. As stated earlier, this presents a breakdown in communication and safety if the pilot is unable to determine what the LSE is signaling.

Flight Deck Management

The LSE's efficiency has been extended to include how they manage the flight deck in the immediate area of the helicopter. The instructors stressed that the LSE not only must manage the signaling communication with the pilots but must be continuously scanning the flight deck environment, Primary Flight Control deck status beacons and the helicopter itself for any abnormalities. This increased cognitive load can be trained to some degree and is discussed in detail during the five day LSE school. The real training in the complete situational awareness comes with direct exposure to the flight deck environment. Subsequent discussions focused on the further definition of the LSE flight deck experience.

Scan Pattern

The LSE must be able to monitor the flight deck area not only for the typical hazards for his or her own personal safety but also look for events with the potential for developing into extremely hazardous situations. The scan pattern was described unanimously as continuous and should include at a minimum: the flight deck area, the approaching helicopter, the approach path, the deck status beacons, the LSE's own position on the deck, the catwalks bordering the flight deck and the area surrounding the LSE. The scanning process is mainly visual but hearing and touch are also used to monitor the environment. Currently, there are no real good means of providing this training without actually placing a trainee in the environment with an instructor. The instructors all felt that this would be a good capability to incorporate into the production version of the VVAST device.

We discussed the current state of virtual environment technology and the current and future technological challenges to meet some of these requirements in order to dispel any possible "Hollywood" perceptions of VE/VR systems. The focus of the Phase I effort is to determine the feasibility of such a device and to that end the primary efforts will be on the feasibility study and initial prototype design. The active duty personnel we interviewed were both receptive and supportive of this approach.

The collateral duties of the LSE during the launch and recovery phase include looking for various hazards in, around and headed toward either the helicopter, the landing area or the approach path. The hazards in the landing area may include loose or unsecured gear which may be blown around by the rotor blast; fuel, oil or hydraulic fluid spills which may ignite or provide a slip hazard to personnel and equipment; improperly placed or secured tie down chains on the helicopter; other aircraft and/ or equipment in the rotor arc(s); other aircraft / equipment in the

helicopter's approach or departure path and the flight deck visitor. Loose or unsecured gear such as wheel chocks, tow bars, tie down chains, aircraft mechanic's tool boxes and ladders, loose tools, fasteners and other miscellaneous gear (e.g. pens) may be present on the deck at any time due to the ongoing maintenance and aircraft movement activity. Although several strong administrative control policies are mandated on Foreign Object Damage (FOD) control by the NATOPS program and FOD walk downs are conducted before each launch and recovery cycle, continued vigilance is necessary to prevent loose or unsecured parts and equipment from damaging personnel or aircraft.

While the proper placement of the aircraft on spot for the rotor blade spread, engine start, rotor engagement and launch operations often eliminates potential conflicts between the rotor arcs and nearby aircraft and equipment, the constant pace of flight deck operations requires the LSE to remain vigilant in scanning for potential conflicts to the sides and rear of the helicopter. Tunnel vision can be a problem with LSEs. When the LSE becomes too focused on the helicopter and does not maintain the proper continuous scan pattern, hazardous situations can quickly develop.

The audible monitoring of the approach really doesn't modify the type or pace of the signals that the LSE gives to the pilot. The only caveat to this is if something unusual sound such as a compressor stall or sudden grinding noise is heard. If this occurs, the course of the launch or recovery will change to get the helicopter on deck quickly. Therefore, the LSE must constantly monitor the noise character and level during all operations. The sense of touch is used to detect hot exhaust from nearby aircraft, the rotor down wash and any unusual vibrations or movements from the deck. A sudden air temperature increase is a strong indicator that another aircraft is nearby and the LSE must quickly determine if a hazardous situation exists while he or she is signaling. The sensation of the helicopter's rotor blast is an important feature to the LSE experience. Deck movement such as pitch, roll and heave are often first sensed through the feet and legs as the body compensates for the sudden inputs. The combination of visual and touch sensations may then be used to determine the current ship's movement which in turn may be factored into the signal planning.

Several of the instructors we spoke with had experience working on smaller ship flight decks, they did feel that the tail rotor height of some of the smaller helicopters may present a problem with the deck edge railings on smaller flight decks if the nets were left up. When asked about what features they would like to see incorporated within the simulator for small deck operations, the instructors emphasized the need to continuously check the deck status lights. Many of the hazards found on the larger flight decks such as FOD, loose equipment and unauthorized personnel on the flight deck take on a greater significance on the smaller decks. There isn't as much room on a small flight deck and the LSE must be extra vigilant.

(c) Situational Awareness

A hypothetical approach, recovery and departure of a helicopter to Spot 4 on an aircraft carrier was used as a framework to open the discussions and gather anecdotal experiences for increasing the fidelity of the VVAST device's simulation. One of the instructors described in great detail how he would look for any potential obstructions in the helicopter's approach path as

soon as the helicopter crossed the fantail. He would specifically look for aircraft and equipment parked in the Elevator 4 area and any deck edge antennas. During flight operations where the helicopter approaches the ship on a straight in radar controlled approach up the angled deck, the LSE must monitor the deck status and if the deck is in fact clear for the approaching helicopter. Two instructors placed more emphasis on the deck status beacons as the indicator of a clear deck.

As the aircraft approaches, the LSE should begin to assess the condition of the helicopter visually and audibly. We had inquired about what visual cues the instructors used to confirm visual contact and identify which pilot was flying the helicopter. This discussion identified several subtleties that when incorporated into the VVAST device will substantially increase the simulation's fidelity. Initially, we had estimated that the visual perspective of the helicopter, ship and horizon created an approximate sight picture that the LSE used to switch from the "Land here" signal to the "Move Right" signal. We were trying to determine what visual cues were used as decision criteria so that we could incorporate them in the graphical display design. Visual contact is often determined by the ability to distinguish different body parts on the pilot as the helicopter approaches (day) or discerning the pilot's face reflecting the instrument panel lights (night). What we determined through the interviews was that the LSEs are looking not at the relative angles but at features on the helicopter and the pilots to gauge the distance. A striking consistency in the interviews was that the instructors stated they would look for the safety of flight items and inspect the material condition of the helicopter first before looking at the pilot to ascertain if visual contact had been made.

The time of day and weather dictate what type of approaches the helicopter will fly in accordance with NATOPS guidelines. During Case I and II (day - good weather) flight operations where the helicopter crosses behind the ship then approaches along the port side to land, the LSE should check the aircraft traffic pattern for potential conflicts during the approach and departure phases. Case III (night or bad weather) operations require that the helicopter make a straight-in approach up the angled deck and transition to LSE control once over the deck safely. In both situations, the LSE instructors commented that they will watch the approaching helicopter's movement carefully to gauge what kind of pilot (e.g. nugget or experienced) they have flying. Even from a distance, the aircraft's attitude (yaw, pitch and roll) provides valuable visual information on both the quality of pilot flying and what condition the helicopter is in. An irregular flight path suggests that there may be a problem with the helicopter and that the pilots need to land as soon as possible. If the flight path is essentially normal but the helicopter seems to slide through turns or be a little slower to stabilize to a hover, it suggests that the pilot may be inexperienced or have something inside the cockpit to deal with. Several instructors commented that the experienced pilots tended to make their approaches fast and low while the newer pilots would come in slow and high. Experienced pilots will typically respond to signals in three to five seconds while the new pilots would take approximately five to ten seconds to respond to the same signal. It is unclear how much of this small time difference is the result of pilot experience and signal anticipation.

Several features that suggested a nugget pilot was at the controls were identified by the instructors. These criteria may also reflect that the pilot is distracted by a problem inside the cockpit and include a subjective evaluation of:

(1) How does the pilot hold the helicopter in a hover?
(2) Is the hover smooth or full of abrupt, jerky movements?
(3) Does the helicopter drift forward during a signaled descent?
(4) Does the helicopter drift backward during a signaled descent?
(5) Is the pilot trying to reposition the helicopter after the LSE has signaled a hover?
(6) Is the pilot anticipating the LSE's signals?
(7) Does the pilot stop the helicopter quickly or slowly when signaled by the LSE?
(8) Does the pilot need encouragement to land the helicopter?
(9) Does the pilot turn the wrong way when a move or pedal turn is signaled?
(10) Does the pilot appear to be paying attention to the LSE's signals?

All instructors indicated that they tend to be more cautious in this situation than with a smoothly flown helicopter and will attempt to slow the pace down somewhat if possible to increase the safety margin. The concept of "never push a bad landing" was emphasized by two of the instructors as a point they really try to teach the students. All of the personnel we interviewed stated that the LSE should not get impatient with a slow pilot and deviate from proper signaling form. Any displays of irritation through body language was considered unprofessional and strongly discouraged by the instructors. If the pilot is fairly new, the LSE may try to lead the pilot's moves a little more by anticipating his or her next move. The experienced LSE will try to make the signals just a little more crisp.

In the day Case I recovery, the senior instructor commented that he began to signal "Land here" as the helicopter is abeam the fan tail and heading up the port side of the CVN. On smaller decks and when based ashore, the LSE will begin signaling when the helicopter is approximately 100 yards away. This distance varied among instructors from 100 yards to 500 yards and may be due in part to the various helicopter characteristics. The LSE will be signaling "Move Forward" as the aircraft continues up the left side until it is past any obstructions such as aircraft parked near Elevator 4. Ideally, the students are taught to bring the helicopter over the deck aft of the landing spot then slowly move them forward to the intended landing area. The LSE will not use this technique if the intended landing area or "spot" is bracketed by other aircraft on the deck. This gives the pilot a chance to deal with a small wobble (roll oscillation) that occurs when the rotor disk crosses the deck edge and get stabilized before the final approach to landing. If the pilot is having to fight the burble, some LSEs will signal a "Move Up" to give the pilot a chance to stabilize the helicopter before proceeding with the approach. The same general pattern holds for the Case III and night recoveries except that the helicopter flies a straight in approach until it is over the deck and control is turned over to the LSE.

Once the helicopter is over the point of intended landing, the LSE will begin to signal "Move Down." When the lowest helicopter landing gear is roughly three or four feet from the ground, he should signal "Land." It is at this point that the LSE should be factoring deck movement into the signaling. In the case of substantial deck movement, the LSEs are trained to bring the helicopter in slightly higher than a normal approach.

(d) General LSE experience features

The instructors all emphasized that a continuous visual scan that includes the flight deck, the approaching helicopter, the port (and starboard where visible) catwalks, the deck status beacons and landing area is necessary at all times. A consistent comment was that the trainees all tend to get tunnel vision on their first few field sessions. LT Marshall (HC-3) indicated that this can happen even with experienced LSEs and both pilots and LSEs have to be vigilant. She also commented that flicker vertigo has also been a problem for pilots and LSEs and may be most prevalent when flying into or out of the sun. This condition results in a temporary loss of balance. The LSE must often reposition himself to maintain visual contact with the pilot which must also be incorporated in the scan pattern. The instructors felt that three to five "stutter" steps was about the average for the shipboard recovery. Tunnel vision can be a problem for LSEs ashore also. *Mech* magazine reported the story of an LSE who backed over a sea wall and fell into a river while signaling to a departing squadron helicopter at a naval air station.

It is critical that the LSE maintain visual contact with the pilot during the evolution. This requires the LSE to ascertain which pilot is flying the helicopter and automatically move to the position that maximizes the potential for continuous visual contact. The running lights may be used as indicators of which pilot is flying the helicopter. If the red and green running lights are bright and constantly illuminated, then the right seat is flying. If the running lights are dim and flashing, the left seat is flying. This small visual cue provides the LSE with an indicator of what direction he or she will have to move to maintain continuous visibility with the pilot flying the approach. The constant or flashing lights are not used on the Sea Knight helicopters. Although the CH-46 almost always touches down on the rear wheels, there are subtle cues that indicate which pilot is flying the approach. In the absence of any direct information on which pilot is flying (i.e. radio call from the Air Boss or Helicopter Control Officer, wave from the pilot not at the controls), several instructors indicated that they are able to tell which pilot is flying by looking for what direction the helicopter yaws to as it approaches. The yaw direction does suggest which rear wheel on the Sea Knight is going to touch down first.

Each helicopter has its idiosyncracies during the launch and recovery phases. These are discussed during the didactic portion of the training, including subtle features such as the tendency of the SH-60 to touch down on the wheel that is on the same side as the pilot who is flying the approach. The SH-2 has a reputation for weak brakes and an LSE instructor with Sea Sprite experience stated that wheel chocks, tie down chains and gear safety pins should be applied as soon as the helicopter lands. The HH-65 has a ducted fan tail rotor that should be treated more like a jet engine intake than a tail rotor as far as deck handling procedures are concerned.

Although each aircraft has a particular sound, there are certain common characteristics. When the helicopter begins to tilt the rotor disk in a turn or climb, there is a thumping or clapping noise that subsides as the rotor disk is leveled. This was described as a "deep thumping" noise for the SH-60 and more of a chopping sound for the CH-46. The CH-46 Sea Knight has three distinct noises: Engine noise, prop or rotor noise and gear box noise. The instructors we interviewed had LSE experience with several helicopter models including the AH-1S/W, UH-1B, SH-2, SH-3, CH-46, CH/MH-53 and HH-65 models. The smaller helicopters

were not a major concern relative to the Sea Knight, Seahawk and Sea Stallion. The latter generates a healthy amount of respect due to sheer size and rotor blast magnitude.

The instructors had mixed opinions about how they personally handle working with a helicopter they had never worked with before. One commented that he will treat a helicopter he has never worked with before much like a CH-53 until its landing characteristics are proven otherwise. Another moves a little farther back and leans into the rotor blast more with an unfamiliar helicopter. Another instructor will note the edge of the helicopter's rotor arc relative to his own position. Other instructors stated that they tend to estimate the helicopter's maneuverability during the approach phase and subsequently modify their signaling routine as necessary to ensure a safe evolution. The modifications may include increased lead time between when a signal is given and what response is desired.

In terms of developing the VVAST device, these comments did provide insight into the alternative methods used by the LSE to compliment his visual scan pattern. All instructors talked extensively about the sensations associated with the rotor blast. Most trainees tend to underestimate the force of the rotor blast from a medium helicopter such as the SH-60 or CH-46 and consequently stand erect facing the helicopter. After the subsequent loss of balance, they will adopt the same support technique utilized by experienced LSEs who place one foot 12 to 18 inches behind them. This additional support effectively balances most rotor wash. In the event that the LSE does stumble or slip and fall, the guidance was to try to put the helicopter in a hover while balance is regained. This direction was extended by one instructor to include anytime that the LSE feels the evolution is getting unsafe. Two instructors commented that the LSE should continue his signaling routine while taking measures to regain his balance.

(e) Hazardous and Emergency Situations

A myriad of hazardous and emergency situations may develop during the normal course of the LSE's duties. Safety issues limit the coverage of this material to almost exclusively classroom discussions at the present time. The effects of inclement weather and the corresponding poor visibility were mentioned by several instructors. The proposed device provides an excellent opportunity to for the trainees to practice signaling under simulated Instrument Meteorological Conditions (IMC) without the risks of live operation training under in poor weather.

Wind Related Conditions

The wind direction and speed are critical parameters that affect shipboard helicopter operations. There are wind velocity (a vector that has both a direction and speed) limits for engine start, rotor engagement, take off, landing and rotor disengagement of each helicopter model. These limits are discussed in Naval Warfare Publication 42 (NWP-42) and in the respective helicopter NATOPS Flight Manuals. The wind vector also affects the performance and behavior of the approaching helicopter. Windsocks and flags can provide a visual indication of the winds near the flight deck although there is some unpredictability resulting from the effects of the superstructure. Tail rotor equipped helicopters are more sensitive to wind direction and speed than twin rotor models such as the CH-46. The speed and direction of the winds in a shipboard environment may be a natural, produced entirely by the ship's movement or a combination of the two. The pilots commented that visual wind indicators such as the wind sock or flags are not always accurate in the landing area. The winds also affect the relative rate of approach of the helicopter to the ship and thus partially affect the operational tempo. The capability of the simulator to include different wind directions and velocities would be a significant feature that would increase the fidelity of the proposed device.

Ground Related Emergencies

There are several ground related emergencies identified earlier in the PQS discussion that the personnel we interviewed would like to see incorporated into the production version of the proposed device. Tie down chains are naturally a major area of concern along with fires from various sources. Additional experiences discussed by the instructors included personnel, FOD and equipment in the landing area, obstacles in the approach path or landing area and helicopters moving beyond limits imposed by deck markings such as the T line and T-Ball lines. These markings delineate the limits of safe operation for various helicopter models and are described in multiple publications including the annually updated Shipboard Aviation Facility Resume (NAEC - ENG-7576). This publication describes the landing area certifications for each air capable ship and type of helicopters. **Tie Down Chains** Improperly placed or secured tie down chains are a feature of the LSE flight deck experience that should be incorporated into the production version of the VVAST device. Tie down chains are used to secure the helicopter when it is not engaged in actual flight operations and are the last items removed before the helicopter's launch. An improperly secured tie down chain may fail at a load far below its 10,000 lb tensile strength limit if it is placed improperly and suddenly loaded as the ship moves significantly. There are at least one dozen tie down points on each aircraft. Tie down chains are

attached to fixtures on the aircraft fuselage and landing gear. The actual locations are specified in each aircraft's NATOPS operating manual. The low point tie down points are used for routine operations. They are used to secure the aircraft just prior to launch and just after recovery. The high point tie downs are to be used when the aircraft is to be secured for some period of time and in all heavy sea states. The high point tie down points are located higher on the fuselage and act to reinforce the restraining forces placed on the helicopter by the low point tie downs.

Ground resonance A critical feature of this securing system must be foremost in the LSE's mind during helicopter operations. Let's assume for a minute that both low point and high point tie down chains are on the helicopter (the number of chains required varies with aircraft type) and properly secured. When the engines are started, there is some understandable vibration imparted to the airframe. When the rotors are engaged, there is substantially more vibration applied to the airframe. The only way for the airframe to dissipate that vibration is through some type of shock absorbing system such as the landing gear strut oleo assemblies. In the test case where taut tie down chains are on both the low (i.e. below the oleo struts) and high (i.e. above the oleo struts) point tie downs of a helicopter that is engaging rotors, there is no real method for absorbing the vibration.

Therefore, the phenomenon of "ground resonance" develops. This situation occurs when a series of vibrations are imparted to the moving rotor blades leading to an unbalanced condition. If the oscillatory condition were to continue to develop, a natural resonance frequency of the airframe components can be reached. As this natural resonant frequency is reached, the amplitude of the oscillation increases dramatically. Unless this situation is corrected immediately, a self-energizing oscillation between the rotor disk and the fuselage develops and massive structural failure of the helicopter will result. Clearly, this is an undesirable event that cannot be demonstrated in the live training environment but must be emphasized to the trainees. The proposed VVAST device is an ideal resource in which this type of experience could be demonstrated in a safe, cost effective manner for the LSE students.

The instructors would like to have the ability to train a student to specifically look for high point tie downs prior to giving the Engage Rotors signal. Currently, this is only a classroom discussion due to the safety related concerns of a live demonstration. The same can be said for incorporating a means of demonstrating the effects of taking off with one or more tie down chains still attached. This point was discussed by all instructors independently.

Rotor brake failure The diagnosis and proper handling of a rotor brake failure during rotor engagement is another situation that can be presented to the trainees in the proposed device that is impractical in a live demonstration. One indication of a rotor brake failure during engagement is a fire around the rotor mast as the pucks overheat from the friction. This situation could easily be incorporated into the proposed device that is not practical or prudent to create live due to the fire hazard.

Miscellaneous emergencies All personnel commented that it would be great if the proposed simulator would enable them to introduce various hazardous and emergency situations to the training scenarios that they can only discuss in the classroom presently. This would allow the trainees to gain actual experience in the thought processes necessary to appropriately handle the

emergency instead of passively listening to directions.

Small flight decks The smaller flight decks such as those found on cruisers, frigates and other air capable ships may not have other aircraft to contend with but have their own set of potential hazards. While a heading change on an aircraft carrier might not produce much deck movement, the smaller ships can have significantly more deck movement in normal operations. Deck edge equipment such as railings and antennas can provide additional challenges to the LSE's scan pattern. This can be especially important when an aircraft carrier trained and experienced LSE works on the deck of a smaller ship. It would be beneficial to incorporate different deck presentations into the proposed VVAST device to provide a more in depth training environment according to the instructors.

Unauthorized personnel The flight deck visitor is a constant problem for all flight deck personnel. This refers to anyone who attempts to enter the flight deck inappropriately through one of the many access points. The purpose of the visit may typically be to observe flight operations and more often than not the visitor is not dressed in proper flight deck uniform. This is an extremely dangerous situation as an unobserved visitor who is not familiar with the flight deck environment can get injured or killed very quickly. The requirement for constant vigilance on the flight deck applies to all flight deck personnel, not just the LSE. Therefore, the scan pattern for the LSE, Primary Flight Control and the flight deck crew must include checks of the catwalks for unauthorized personnel.

Airborne Related Emergencies

The LSE is visually scanning the approaching helicopter for any abnormalities that may represent a safety of flight item as it approaches. This includes the flight path and attitude, loose, bent or missing panels, antennas and / or landing gear and smoke or fluid leaks. The visual scan continues until the helicopter is safe on deck or has departed the area. In the event of a visible abnormality, the LSE may alter his signaling plan as necessary to safely recover the helicopter.

Summary

The purpose of this objective was to identify the features of the LSE's environment and which tangible and intangible factors are appropriate for the initial prototype design. It is clear that there is much that can be said about the details of the duties and responsibilities of this individual. We have been fortunate in having the opportunity to meet and discuss the nature with over a dozen experts in the field. Their comments, insights and experiences have helped define the features and observable characteristics necessary to increase the fidelity of the virtual environment.

Tangible features

Tangible features may be thought of as adherence to established policies, procedures and practices. Does the device provide a way to train students in a realistic manner? In order to

answer this question, several areas must be addressed aside from the standard graphical display issues (i.e. "Does the display look like a flight deck?"). The first priority is to establish a method of controlling the virtual world with appropriate hand signals while improper hand signals are not recognized. In view of the variability inherent in the way the hand signals are performed, the motion capture system must allow for some limited margin for error in the signal profiles before allowing the image to update. There should be some means of displaying the proper signals for the trainee to emulate once the simulation is resumed to reinforce the educational process.

The motion analysis/ pattern recognition system should not be rigid enough that a standard signal pattern may be learned and passed from graduate to student in such a way that the student can successfully complete the simulator without facing the intended educational challenges. This criteria suggests that the device must allow the trainee to inadvertently place the simulated helicopter in mishap situations without limits. Therefore, the consequences of situationally inappropriate signals (e.g. a Move Forward signal when the helicopter is already forward of the T line leading to a blade strike with the ship's superstructure) can be demonstrated without risk to personnel and equipment.

This leads into the incorporation of both ground and airborne hazardous and emergency situations. While there are a multitude of potential emergencies that may be simulated with the different types of helicopters in the inventory, it is crucial that one platform be chosen to focus on for the prototype. It is intended that the production version of this device will allow the instructors to select a particular helicopter model for the training operation from a pull down menu. Therefore, it will be necessary to structure the virtual helicopter model in a sufficiently generic framework to facilitate future model additions. The interviews and literature reviews have identified a substantial number of tangible factors that should be incorporated in the proposed device. The prioritization of these features should follow the guidelines of the LSE PQS in order to maximize the device's acceptance potential. The deployment of the proposed device in the personal computer environment does present a tremendous supporting role for use by the LSE School mobile training teams. It is conceivable that the cost savings this device would produce may be shared by the outlying active and reserve commands if the production version device was transportable.

Intangible factors

A significant factor in creating a sense of presence in the virtual environment user requires that the objects within the virtual world appear, move and sound like the real world objects. Recent advances in computer graphics have produced photo-realistic rendering in both still pictures and sequenced animation but at a substantial processing overhead. Digital Video Display (DVD) offers a substantial improvement in the display possibilities when it becomes available next year. The audio component of the synthetic environment must be perfectly synchronized with the visual displays to create a sense of presence. The tactile sensations associated with the wind over the deck and rotor wash are important parameters used by experienced LSEs to monitor the evolutions progress. Users may be willing to accept the virtual environment presentation with a little less intensive graphics if the objects move, sound and feel like the real world. In order to create the presence illusion, it is necessary to ensure that the objects move appropriately in perspective, depth with realistic (i.e. nonlinear) acceleration and

velocity profiles. The use of three dimensional sound technology can enhance this illusion by linking the virtual image location to the virtual sound source. Unfortunately, this audio technology is in its infancy but substantial amount of work is occurring in the area. Subsequent technical objectives are designed to develop the components necessary to generate the sense of presence for the user.

TECHNOLOGY EVALUATION

The key technical challenge in the VVAST prototype development is the creation of some method to capture the hand signals from the LSE that is as transparent as possible to the LSE students and instructors yet robustly determines what is being signaled. It is first necessary to analyze the original movements to determine what features may potentially be extracted for use in the pattern recognition module. A biomechanical evaluation of each of the standard hand signals was conducted to determine the movement's temporal and spatial characteristics. Acceptable and unacceptable movements, minor variations and common errors were identified to facilitate the proper classification of the movement. Concurrently with the movement analysis, an evaluative survey of current, emerging and novel motion capture technologies was made. While a myriad of motion capture systems exist, it was also clear that none were able to support the all of the variations in the LSE training system. Emerging technologies provided some interesting possibilities that also met only a portion of the system requirements. Several innovative concepts tailored to the LSE training environment are under development.

BIOMECHANICAL ANALYSIS

It is necessary to classify and prioritize the NATOPS specified hand signals in order to develop the detailed requirements for the motion capture and analysis module. A review of the Aircraft Signals NATOPS Manual (NAVAIR 00-80T-113) and the site visits have provided a substantial amount of data that includes proper and improperly performed hand signals. The data also reflects the use of appropriately sequenced signals relative to the helicopter operation.

Hand Signal Analysis

There are thirty five helicopter handling signals that are given by the LSE. They may be classified as cyclical or burst signals. The former are signals in which a set of smaller movements is repeated for as long as the LSE deems it necessary for the pilot to take the desired action. Once the pilot has maneuvered the helicopter to the position the LSE wants, the LSE will then switch to another signal. The subsequent signal may be another cyclic or burst signal. The latter category represents those signals where a few rapid movements involving one or more segments are made to place the arms in the desired signal position. Once in the proper position, the arms are held there until confirmation that the signal has been understood is received from whoever the signal was directed at (pilot, crew member or deck crew). Burst signals by definition are shorter than continuous signals although the sub-movements that comprise the continuous signals may be on the same order of time.

Continuous signals are primarily used as attention getting devices and for directional control of the helicopter. This category consists of the following signals: Land Here, Move Forward, Move Back, Move Left, Pedal Turn Left, Pedal Turn Right, Move Right, Move Up, Move Down, Wave Off, Hook Up Load and Release Load. Six more hand signals have cyclical components to them although we did not observe them in the three pad sessions we attended. These are the Cut Cable, Lower Wheels, Engage Rotors, Winch Up and Winch Down. Each of these movements has one or more arm segments (arm, forearm or hand) making a particular motion (e.g. circular) repeatedly for the duration of the signal.

Burst type hand signals include Hover, Hold, Land, Clearing Turn, Take Off, Droop Stops In, Droop Stops Out, Remove Blade Tie-downs, Load Has Not Released, Spread Pylon, Fold Pylon, Ready to Engage Rotors, Ready for Take Off, Remove Tie Downs, Disengage Rotors and Antenna in the Down Position. During the three pad sessions we attended, only the first five burst signals were observed.

While the majority of hand signals are given in routine taxi, takeoff and landing operations, it should be noted that there are several hand signals that are only given in hazardous or emergency situations. It is neither practical or prudent to create this type of situation in a training environment just to allow the trainee the opportunity to perform the signal. The Wave Off, Hold and Load Has Not Released are three examples of signals that represent hazardous situations that the LSE trainee may have to face in the normal pad training sessions. Signals such as the Droop Stops In/Out, Cut Cable and Antenna in the Down position represent situations that are hazardous and not appropriate to create for the training session with a live helicopter. The proposed VVAST device provides an excellent opportunity to provide the trainee with experience in recognizing and handling potentially catastrophic situations without risk to personnel and equipment.

Reference Frames

Three mutually orthogonal planes are used to describe the biomechanics of each hand signal. The Sagittal plane divides the body into left and right halves along the center of the body. The Frontal Plane divides the body into front and back halves and is centered on the long axis of the torso. The Transverse plane is located at the waist and divides the body into upper and lower halves. The majority of the movements are contained within the Sagittal and Frontal planes. This is a standard anatomical convention and provides a link between the movement and the three dimensional reference frames that may be associated with a fixed location in space. Therefore, this may provide a means of linking the relative joint angle rotations to an absolute frame of reference. The biomechanical model which began at thirteen degrees of freedom has been substantially simplified to remove some unnecessary complexity following observations made during the site visits. This model enables the theoretical generation of movement profiles in the absolute frames of reference within certain constraints.

Modeling and Simulation

Three dimensional musculo-skeletal models are useful in determining a limb segment's trajectory in space given a set of muscle forces. The same models can also be used to estimate the muscle forces required to produce and experimentally observed trajectory. Although most biomechanical problems are statically indeterminate (redundant muscle forces may prevent a unique solution), this technique does provide a framework to investigate the contribution of individual components of a complex hand signal. Each degree of freedom represents rotation of one segment about a physical or analytical axis based on another segment. Therefore, the muscle moments that produce rotation about an individual axis may work in concert to produce a complex movement. The difficulty in this type of analysis is that the relative magnitude and timing of the muscle activations becomes critical. There are many potential solutions to the equation that describes the global trajectory of the movement. In pure biomechanical research,

the interest is in how the individual muscle force activation onsets, durations and magnitudes combine to produce the observable trajectory. While an interesting area and one that would be an excellent academic neuromuscular investigation, the results of this type of study would not substantially benefit the Phase I effort in the form of movement profiles as we once thought.

The trial and error process necessary to duplicate a proper signal such as the Move Up was more time consuming. The modeling effort did show that the effects of intersegmental dynamics (where the movement of one segment imparts a small movement to each of the other segments) were insignificant in terms of magnitude when compared to the magnitude of the movements in the arm signals. Therefore, the model complexity can be reduced even further to eliminate those effects. The attempt to emulate the experimentally observed signals in terms of timing became a significant computational effort. The bottom line in movement model complexity is the issue of "Do the minor variations significantly affect the overall process and, if so, how much is the safety of the evolution affected?" Although the minor deviations from the ideal signals are important to the final product, the Phase I effort is intended to determine the feasibility of the proposed device. The quantification of each individual variation pattern for each signal is reserved for the Phase II effort.

If one examines the basic movements of one arm used to create the standard LSE hand signals, the primitive motions can be classified into six categories. Shoulder abduction and adduction describes the raising and lowering of the extended arm in the frontal plane respectively. Shoulder forward flexion and extension describes the rotation of the anterior and posterior rotation of the arm such as that observed in the Move Back signal. Internal and external rotation of the humerus (the bone in the upper arm) produces a turning movement of the forearm about the long axis of the arm. Elbow flexion and extension is the standard means of lifting and lowering and object using only the arm. The radial-ulnar deviation of the wrist is a side to side movement of the hand on an axis perpendicular to both the long axis of the forearm and line of wrist flexion and extension.

Six movement axes have been used to describe rotation in the three joints in the arm during the primitive motions that are used to construct the standard hand signals. The models were simplified to simply duplicate the observed joint angle timing sequences. The variations seen in the videotaped data across LSEs produced markedly different joint angle trajectories. The results are explained in more detail under the subsequent sections that describe each hand signal. There are a few general trends that need to be discussed. We have commented that the duration of the individual hand signals had so much variability due to the global situation and speed of the approaching helicopter that a detailed statistical analysis of the data would not substantially further the VVAST device development. The analysis was then extended to look at the times associated with the primitive movements that make up the standard hand signals. It was here that the true temporal nature and the technical challenges of the hand signals became apparent.

Kinematic Data

The directional signals all have a continuous repetitive nature to them that ideally is sinusoidal. In other words, a common interpretation of the descriptions of these signals in the Aircraft Signals NATOPS Manual is that they are intended to be performed continuously while the helicopter completes the desired response. As discussed earlier, there is plenty of room for some individual variability without a significant degradation in the clarity of the signal to the pilot. Figure 1 illustrates the shoulder abduction-adduction angle for a series of properly performed movements where the motion was constrained to the sagittal plane. The curves are approximated from videotaped data on two LSE instructors giving the Move Up signal.

The kinematic data presented here was reconstructed from the videotaped movements by LSE instructors and students obtained during both site visits and illustrates several characteristics of the signals. The periodic nature of the cyclical signal can vary over a range without any degradation in the signal meaning by the pilot. This variation can occur in several ways. An increase or decrease in the frequency of the movement holding all other parameters constant will shift the curve left or right respectively. In the upper plot, the instructor is giving a slow, careful Move Up signal as the helicopter was taking off (solid line). Once the helicopter was airborne and had the VERTREP load hooked up but with no tension in the cable, the signal frequency increased significantly (dotted line). The lower plot illustrates the effect of variable length pauses between component movements on the joint angle trajectory.

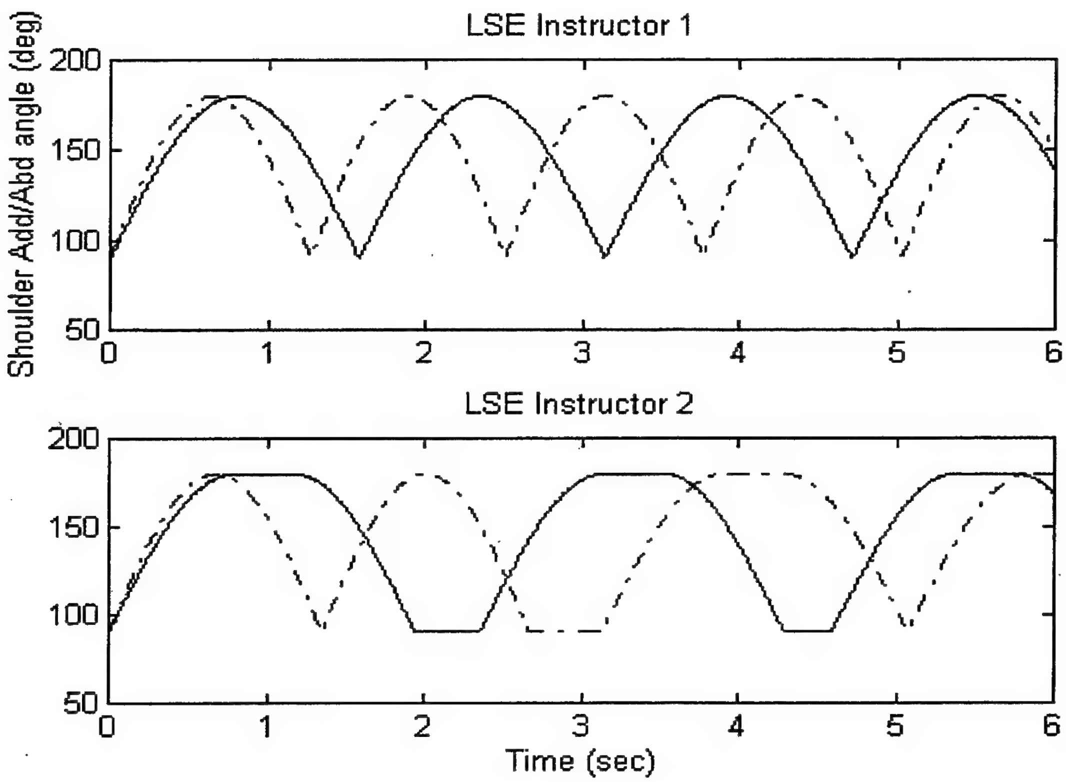

Figure 1. Reconstructed kinematic data from two LSE Instructors

In the first trace (solid line) of the lower plot, the instructor is also giving a slow, careful Move Up signal to the pilot as the helicopter is taking off. This individual's signaling procedure includes pausing between each movement to produce a "crisper and more military" (instructor comment) signal. The second trace represents the Move Up signal given as the helicopter has the VERTREP load attached and is beginning to lift. The pause evident at time = 2.8 seconds may be an attempt to modify the speed of the lift, a delay due to the diversion of the LSE's attention elsewhere (scan pattern) or another reason.

This type of variability was observed in all signals from both students and instructors. What is important to remember in avoiding the "this is interesting..." trap is that within a fairly large range, the individual movement variations do not appear to compromise the speed, character or safety of the evolutions (taxi, take off, landing, VERTREP). Therefore, the production version of the VVAST device must be robust enough to account for the thousands of individual variations and still respond in a timely fashion with appropriate training.

Two general approaches are possible. It is possible to sample and record as much data as possible then remove unnecessary noise from the desired signals through digital signal processing. This approach requires a significant investment in terms of software and hardware. The second approach reduces the sensitivity of the input channels so that the gross movements are detected and finer movements are ignored. While potentially less elegant than the former approach, this method reduces the processing load on the system by eliminating the noise factor early in the processing step. Therefore, it is not as costly in terms of computational resources.

Technical challenges in hand signal analysis

There is a certain amount of latitude allowed the LSE in certain movements such as the Take Off signal where they can insert a little personal flourish for lack of a better term. We observed this on the videotape of the night session. When the LSE would transition from the Clearing Turn signal where the arms are held horizontally and the torso is rotated at the hip and about the spine, some trainees would make a circular motion with the wrist pointed toward the helicopter as they were simultaneously tucking the left arm away and moving the right arm laterally. This motion of the right wrist would be followed immediately by a rapid lateral wrist movement to place the hand in the proper signal position. Obviously, the pilot and LSE understand the signal and are able to proceed accordingly.

Whether the wrist flip which may be a pilot attention getting device from the LSE or simply a statement of personal pride really isn't important, the human components are able to recognize, interpret and react to the brief (several hundred milliseconds) signal without any operational delay. The computer based motion analysis systems must continuously scan the movement profiles to determine if a new signal is being presented and, in the production version of the VVAST device, move the virtual helicopter accordingly. Since the wrist motion does induce a slightly different movement profile to the system, how should the computer react? This is but one example of many small input movements that we need to identify in order to create a pattern classification system robust enough to handle the personal flourishes and recognize improperly timed and performed signals.

We are exploring the potential of slowing down the data acquisition rate to capitalize on the order of magnitude that the signals and responses are given in. In addition to increasing the amount of data recorded, high speed acquisition of motion data does increase the noise factor. The small rapid movements described earlier that are used to emphasize the hover may be troublesome to a high speed data acquisition system. Traditional motion capture technologies such as those evaluated within the scope of this project are focused on collecting joint angles and segmental positions at each instant in time. One of the reasons for this philosophy originates in the clinical research requirements that drove much of the early human motion analysis system designs. Subtle variations in each phase of a movement such as walking are thought to reflect differences in how the muscles are activated which may in turn lead to a deeper understanding of how the neuromuscular system operates.

The purpose of the motion analysis and capture module within the VVAST device is to capture the movements from the LSE trainee to allow the virtual pilot to respond. The benefits of a detailed analysis of the individual variations in hand signal performance may be outweighed by the computational cost to account for the errors and noise in the signals. In order to account for some of the flourishes used by the LSEs (students and instructors), a detailed tracking device must have limits and filters built into the analysis algorithms to separate the non-ideal but acceptable units from the unacceptable units. For simplicity, let's examine the hover signal that is emphasized with a vertical radial-ulnar deviation of the wrist. The amplitude of the movement may be small but just what is the threshold between a small emphasis movement and the timid beginning of a vertical directional signal. It can be seen that the sensitivity of the pattern recognition module must be decreased to reduce the potential for false signal detection and

classification.

The temporal nature of the movements is in the several hundred millisecond range rather than the tens of milliseconds that some of the clinical research is focused on. The hand signals are meant for interpretation by a pilot who may be several hundred feet away from the LSE. Therefore, the motion tracking system may not require +/- 0.1 degree accuracy to track the movements. It has been made extremely clear by the fleet personnel we've interviewed that the hand signals should be given at a smooth and even pace. Fast or rushed signals are considered unacceptable and may in fact be ignored by the pilots. As this device is meant for a training application, there are going to be significant percentages of error prone input signals. In order for the pattern recognition module to classify each input as acceptable or unacceptable, an extensive characterization of the common errors and variations of each signal needs to be made once an appropriate motion capture technology is selected.

The relative coarseness of the movements to be analyzed (as opposed to the detailed analysis of a pitcher's fast ball to find the extra ball speed) is a significant advantage in reducing the complexity of the motion capture requirements. The fleet requirement to deem fast or rushed signals as unacceptable compliments this. However, even if the sampling methodology and frequency are reduced, the Nyquist criteria must still be satisfied to prevent aliasing of the signal. Once the data has been acquired, it is fed directly to the signal processing algorithms. The choice of which algorithm is best for the signal processing is complicated by the need to define the collection time windows. In order to recognize a pattern in time domain data, it is necessary to declare a standard time window that the pattern definitions are then based on. Certain classical processing algorithms require a fixed number of points to operate with any real speed. This can place additional constraints on the time window definition. In view of the variations present in the temporal nature of the hand signals observed from expert and novice LSEs before any signal processing is done, it is clear that substantial work remains to be done before automated error free hand signal recognition is a reality.

The patterns used for the recognition module should be properly performed standard hand signals. This approach will enhance the training process by allowing only those signals performed in accordance with NATOPS to manipulate the virtual helicopter. Only those signals that were observed during the site visits will be included in the initial design for time consideration. After the prototype is operational, additional signals can be added as necessary to extend the simulator's capabilities.

Cyclical signals

A few words about the signal duration time measurements are necessary. The signal durations were recorded off the video tape initially. During the second site visit, we recorded signal times directly with a hand stop watch to validate the times recorded from the videotapes. Although a detailed analysis of the recorded duration times may not be worthwhile, the range of data does indicate some potential means of discriminating good and bad signals. It is promising that the temporal nature of the signals is on the order of seconds and not milliseconds. We have adopted the convention of reporting the time values in milliseconds instead of decimal portions of a second. This decision was made for readability and it should be understood that the reported

times are averages of manually timed values.

Land Here

This signal begins with the LSE standing with both arms extended vertically. The arms are simultaneously lowered to the horizontal pointing at the intended landing area. The main rotation in this sagittal plane movement occurs at the shoulders. There is not supposed to be any elbow or wrist rotation during the movement. Once the arms reach the horizontal position, the LSE may pause for a short time before raising the arms or immediately raise them. Either mode is an acceptable variation. Potential errors of this signal include bending the arms at the elbow during the vertical movements which may produce a "Move Forward" signal. Since this is typically the first signal given to the approaching helicopter, the duration of this signal is dependent on how far away the helicopter is when the signal is initiated.

If a pause was included in the movement, it typically occurred when the arms were horizontal although some trainees would pause at both ends of the movement. This signal was usually followed by the Move Forward signal. The transition to the Move Forward signal is essentially seamless in that most individuals would wait until their arms were horizontal then flex the elbows instead of the shoulders to create the new signal. It is important to note that there was very little difference noted in the frequency of movement during the transition. Any changes in frequency that did occur happened well after the new signal was established. These changes typically resulted from the LSE holding their hands/wands on either side of their head to emphasize the Move Forward signal instead of Land Here. This signal was observed in nearly all field training sessions provided the student was in place and ready before the helicopter reached the short final approach position.

Move Forward

The Move Forward signal is very similar to the Land Here signal except that the arms are held horizontal and the primary movement is in the sagittal plane with all rotation occurring about the elbow. There should not be any shoulder or wrist movement with this signal. We did observe an acceptable variation of this signal where the wrists are rotated externally during the flexion at the elbows. This causes a day time visible rotation of the palms much like the signals given by a police officer doing traffic control. At night, this variation is transparent to the pilot. A short duration pause may be used by some LSEs as a method of making the signal appear more crisp and may occur at either end of the movement. The duration of this signal is also dependent on the distance and speed of the approaching helicopter. The average cycle times were in the range of 500 milliseconds. This is expected as there is less time required to flex the elbows than move the entire arm. This signal is usually followed by a Hover to stabilize the helicopter before continuing the approach any further.

Move Back

The Move Back signal is mainly a sagittal plane movement performed by rotating the arms forward at the shoulder until they are between 30 and 45 degrees forward in a pushing motion. Although the majority of the rotation is at the shoulder, there is an acceptable variation

where elbow flexion is used to further emphasize the push back motion. An unacceptable variation of this signal is similar to a bench press motion where the arms are pressed forward at shoulder level. This variation is difficult to discern from a distance. This signal is usually given slowly since the backward movement of the helicopter is potentially hazardous. There was some consistent period lengths in the Move Back signals we observed. Most cycle times had a 600 to 650 millisecond forward flexion of the shoulder to produce the signal. The variability was lower than other directional signals. As with most directional signals, this is typically followed by a Hover signal.

Move or Pedal Turn Left/Right

The Pedal Turn signals are also described as Move the aircraft's tail Left/Right. The major difference between the two sets of signals is the angle of the non-moving arm relative to the ground. In the Move L/R signal, the stationary arm is parallel to the ground. The Pedal Turn signal has the LSE point at the ground with the non-moving arm. This is a common source of confusion as some LSEs may drop the stationary arm while distracted or moving. The pilots must determine whether the LSE is calling for a Move (horizontal movement on the same heading) or Pedal Turn (heading change in place) based on the situation.

These four signals are subject to different interpretations. The description in the Aircraft Signals NATOPS Manual suggests that these are rigid arm signals where little or no elbow movement is desired. Trainees performing the directional signals may use the whole arm or the bend at the elbows style as long as the character of the movement is obvious. While either style is acceptable, there are some intermediate regions between the two styles that are unacceptable. The period lengths also reflect a difference based on what style is used to produce the signal. Rigid arm signals are averaging out to a 700 to 800 millisecond period length while the bent elbow signals are showing averages right around 500 milliseconds. It is clear that there must be a wider range of allowable movements built into the proposed device to allow for the existing acceptable variations of the NATOPS specified movement. These signals are also typically followed by a Hover to stabilize the helicopter.

Move Up/Down

This set of signals are near mirror images that consist of mainly frontal plane movement by arm abduction/adduction. The wrists are rotated such that the palms face the direction of intended movement. Although no elbow flexion/extension is called for in the movement description, several minor elbow movements have been noted on the return movement (i.e. movement opposite the intended direction being signaled). This was more predominant on the Move Up signal as it is easier to drop the elbows and let gravity help brings the arms back to the horizontal faster. However, it was also observed that several students would use "snap" type movements (a rapid limb movement to and from a point such as striking a nail with a hammer) in these signals. The instructors commented that this is not an appropriate type of movement.

While these do not appear to affect the pilot's interpretation of the signal if the elbow movements are small enough, they can be confusing if combined with forward flexion of the shoulder into the sagittal plane. This secondary movement causes the arms to rotate forward thus

changing the plane of movement from the frontal to more of an oblique plane. If the shoulder is flexed too far forward, the Move Up signal can begin to appear like a Move Forward signal. If the LSE allows his arms to cross over his head, the signal becomes the mandatory Wave Off signal.

The period length of the directional signals as a whole and the Move Up/Down signals in particular is really dependent on the stage of the evolution when the signal is given. If the helicopter is lifting off the ground, the signals may be a little slower than if the airborne helicopter is lifting a VERTREP load. As discussed previously, constant speed signals are desired and ideal but the reality is that there are some situationally based differences. The cycle times we observed were averaging around 700 milliseconds for instructors and anywhere from 600 to 1200 milliseconds across students. Those trainees who would pause between movements were not consistent in where the pauses would be placed or how long they would last. This detail is important in trying to determine the acquisition parameters.

The Move Up signal may be followed by a Hover, Clearing Turn or Take Off signal during normal operations. Clearly, it is prudent to issue a Clearing Turn prior to the Take Off Signal although this does not always happen. Both pilots and instructors have commented that this error is a continual problem that they would like to see built into the simulator. The Move Down Signal may be followed by a Hover, Land, Hook Up Load or Release Load Signal. Both schools teach that a Move Down signal should be followed by a hover to stabilize the helicopter. The field sessions showed that the Move Down signal was often followed by the Hook Up or Release Load signal as the pilot automatically entered a hover. It would be advantageous to include both options into the proposed VVAST device to avoid the development or training of complacency in giving the Move Down signal.

Wave Off

This is one of two hand signals requiring mandatory compliance by the pilot. It is very similar to the Move Up signal except that the hands actually cross above the head. This signal is given anytime the LSE feels the approach is outside of safe limits and may be very fast and exaggerated depending on the situation. The videotape analysis of this signal really requires a fore or aft perspective due to parallax making a properly performed, if not slightly exuberant, Move Up signal appear as a Wave Off.

Hook Up Load

The Hook Up Load signal is actually a complex series of multi-joint rotations and flexion/extensions to produce a sagittal plane rope climbing motion in front of the LSE. The movement includes continuous abduction/adduction of the shoulders coupled with an ongoing elbow flexion-extension to produce the climbing movement. The individual arm movement cycles are typically opposite in phase and equal in magnitude. At the conclusion of the movement, the clenched fists may be brought together or held a few inches apart vertically. The period lengths of this signal are fairly consistent in an individual once they settle into a comfortable rhythm. However, the individual's level of excitement can affect the duration. An excited LSE may give the Hook Up signal with a 500 millisecond average period. A more

cautious LSE may be giving the same signal with a cycle time nearing or even passing one second. Both signals appear to be clear to all personnel involved in the evolution.

This signal may be given as long as the Hook Up Man (and any other personnel) are under the helicopter (ten to fifteen seconds) or simply as a brief signal to the Hook Up Man followed by a hover signal to the pilot while the load is attached to the helicopter. Both styles were observed during the site visits. Therefore, the motion analysis system must be flexible enough to allow both styles unless a NATOPS change dictates otherwise.

The period of the individual movements in this signal are fairly constant once the LSE settles down into a rhythm. The period ranged from 430 to 700 milliseconds with the average half cycle lasting just over 500 milliseconds. Instructors and trainees were fairly consistent within their own signal. The largest variation with students occurred when the student tried to place the hand or wand exactly on top of the lower hand/wand. The additional accuracy did not affect the meaning of the movement but added a few hundred milliseconds to the cycle time. As one might expect logically, the magnitude of the movements in terms of angular displacement was larger when the LSE was using flashlight wands. This signal is usually followed by a Hover signal.

Release Load/ Cut Cable

The Release Load signal is a near mirror image of the Cut Cable signal. The mirror axis can be thought of as the sagittal plane. The former consists of an forward and horizontally extended left arm with the extended right arm making vertical pendulum type movements. The Cut Cable signal extends the right arm and moves the left arm horizontally. Both arm movements are below the extended arm. In practice, the right arm movement in the Release Load signal may become more horizontal than vertical. The period of the moving arm in the Release Load signal varied from 400 to 700 milliseconds. A few trainees were giving faster signals but their speed was consistent with their style.

We did not observe a Cut Cable signal during the site visits. Cutting the cable is considered an emergency procedure and presents an immediate danger to the aircrewman, helicopter and ground personnel. Therefore, this procedure is not prudent or practical in training evolutions. Both signals are usually followed by a Hover signal.

Lower Wheels

This is a continuous small magnitude movement including combined forward flexion/backward extension of the arm and elbow flexion and extension to produce a circular motion of the hands in front of the LSE. The signal is given as the LSE has turned to one side so that the circular movements are viewed from the side. This was not observed in the site visits as the helicopters we observed had fixed landing gear. The SH-2, SH-3 and the CH/MH-53 have retractable gear. The former two are being phased out of the fleet while the Sea Stallion will be in active service for some time.

Engage Rotors

The Engage Rotors signal is a horizontal circular motion of the right hand held slightly above the head. This is a complex right arm movement produced by an alternating internal and external rotation of the arm and elbow flexion and extension. The left arm is not involved in this signal and may be held at the side. This signal was not observed in the site visits although it is an important component in some of the PQS related hazardous situation topics. A failure of the brake pads to disengage may present as a fire around the mast during rotor engagement.

Winch Up / Down

The two Winch signals are similar to the Release Load signal with the left arm extended in front of the body with a clenched fist. The right arm movement is mainly vertical with direction indicated by the face of the open palm. Elbow flexion and extension is primarily responsible for the sagittal plane movement. The similarity between the two signals at night since flashlight wands are used may require the pilot to use situational awareness to interpret

what the correct action should be. This awareness should be incorporated into the production version of the simulator. These signals were not observed during the pad sessions

Burst Signals

Hover

The Hover signal is simply described as a frontal plane signal with both arms extended laterally and held parallel to the ground. This is also the starting position for nearly all of the directional signals. A multitude of small movements were used by students and instructors to emphasize the signal. These small magnitude motions included rapid frontal plane oscillations (radial-ulnar deviations), fast or slow sagittal plane (wrist flexion-extension) movements or a combination of the two to produce small circles. Additional motions were wrist flipping in either major plane or a combined rapid arm and elbow extension to the horizontal position from the previous signal. There was a substantial amount of variability in which additional movement was used to signify the Hover even within subjects that quantification is difficult at best. The duration of the Hover signal may be anywhere from less than two to over twenty seconds. A common error among the students was to lower the arms from the horizontal position while walking to a new location for improved line of sight with the pilot. This signal can be followed by almost any other signal.

The transition to the hover signal presents a substantial technical challenge. The trajectory of the arms may take an innumerable series of paths to reach the Hover position depending on where the arms were initially. In many cases, this signal is used as a quick, non-verbal indicator that a new signal is about to be given.

Hold

This is the other LSE hand signal requiring mandatory compliance by the pilot. Clenched fists are held at eye level for daylight signals while at night crossed wands are held over the head. This is used primarily when the helicopter is on deck. The instructors reported few students have difficulty learning this signal.

Clearing Turn

The purpose of the clearing turn is to visually check the departure path of the helicopter for other aircraft and obstructions before issuing a Take Off signal. It typically follows a hover signal. The movement consists of a 180 degree side to side turn to visually check the area. The signal may be given by keeping the arms extended and rotating the upper body at the hip from one side to the other while looking for traffic. An acceptable variation of this signal is to only rotate the head during the clearing turn while keeping the body in the Hover signal position. The pilots at both locations commented that they get concerned when the LSE clears them for departure without a visible clearing turn. They would like to have some feature built into the simulator to emphasize the need for a proper clearing turn. In view of the differences in the magnitude of the movements, the motion analysis system must be designed to include both versions of the signals.

Take Off

The Take Off signal is the last standard signal given by the LSE to the departing helicopter and may be followed by a salute depending on the individual. The movement consists of concealing one arm from the pilot's view by placing it behind the LSE's back. The other arm makes one or more quick small circles above the LSE and then points in the intended departure direction. The arm movements are produced by the combined action of the elbow flexion and extension and internal/external rotation of the arm at the shoulder.

Droop Stops In / Out

These signals are only given as the rotor is engaged/disengaged. Both arms are extended over the head with the thumbs of both hands pointing in or out respectively. These signals were not observed during the site visits. The failure of the droop stops to properly position as the rotors disengage can quickly produce an emergency situation on the flight deck. The droop stops are not under cockpit control and creating this hazardous condition for a live training evolution is ill-advised at best. However, the proposed VVAST device is an excellent resource to use in training the LSE students to recognize and handle this condition appropriately.

Remove Blade Tie Downs

This momentary signal consists of the LSE pointing at the individual blade tie down covers with his right arm while holding his left hand over his head. This signal is used before engine start and was not observed during the site visits.

Load Has Not Released

This is a hazardous situation warning signal that is given if the Release Load signal has not been responded to within a reasonable period of time. There may be many reasons why the load hasn't released and once this signal is given, the position is held until either the load is released or the pilot signals a new course of action. This signal was observed once during the second site visit. The nature of this signal is to warn the pilot of a potentially hazardous situation and therefore should be considered for inclusion in the VERTREP portion of the VVAST device.

Spread / Fold Pylon

The Spread Pylon signal consists of a single frontal plane extension of the right arm laterally. The Fold Pylon is the mirror image. This signal was not observed during the site visits as it is not applicable to the helicopters observed in the pad sessions.

Ready to Engage Rotors

This signal is given when the LSE is facing Primary Flight Control by holding the left fist over the LSE's head and making a circular movement with the right hand. This was not observed on either site visit as it is primarily a shipboard signal. It should be included when the helicopter start up sequence module is developed in the Phase II effort.

Ready for Take Off

This is similar to the previous shipboard signal except that a thumbs up signal is given with the right hand instead of the circular motion. It should also be included when the helicopter start up sequence module is developed in the Phase II effort.

Disengage Rotors

The Disengage Rotors sign is given by holding the left fist above the head and making a horizontal cutting motion with the right arm in front of the throat. It would also be an important feature in the helicopter shut down sequence module to be developed in the Phase II effort. This signal was not observed in the site visits as the pad sessions did not include helicopter start up and shut down operations.

Antenna in the Down Position

This is a brief signal consisting of one right elbow extension in the sagittal plane. The left palm is cupped over the right elbow before the extension occurs to give the signal. This signal also warns of a potentially hazardous situation that is not appropriate to create in a live training session.

Signal Transition

The transition between individual hand signals presents a substantial technical challenge. LSE trainees are taught to give the Hover signal after nearly every movement as both a safety feature and a speed control on the evolution. The students are also taught that if they lose their situational awareness momentarily, put the helicopter in a hover and get reoriented to their surroundings. Hence, there are a significant number of signals that start or end in the Hover signal position. Furthermore, the starting position for all directional signals except for the Land Here, Move Forward and Move Back signs is the Hover position. The technical challenge is how to make the motion analysis system realize that the input is a transition between signals or part of a directional signal and not a "Hover."

LSE Hand Signal Data Collection

The site visits provided outstanding opportunities to observe and begin to quantify the various hand signals given during the different training evolutions (i.e. day launches and recoveries, night VERTREP, etc.). Videotape and 35 mm still photography were used to collect several important pieces of data. Several common errors in the standard hand signals were recorded. Two of the more common errors were partial bending of the elbows during a portion of the Move Right, Move Left and Move Forward signals and no arm tuck on the Take Off signal. Other common errors observed included momentary lowering of the arm from the horizontal while walking and giving the hover signal. It is necessary to identify what the potential errors are before the classification of each signal can be completed. Some of the photographic and videotaped data was more difficult to interpret due to the forty plus degree offset from camera location to the LSE training area. The night session photographs did provide some interesting documentation of the common movement errors due to the extended shutter times.

A common error observed in both pad sessions was the overextension of the arms in the Move Up and Move Down signals. Figure 2 shows two examples of this movement variation. The angle by which the trainee's arms moved beyond the horizontal plane was a combination of several factors. These include how fast the trainee was moving their arms in the intended direction, how fast the arms were moving on the return stroke, how fast was the entire evolution going (i.e. was the trainee struggling to keep up with the speed of the helicopter's movements?) and how much was the trainee bending at the waist?

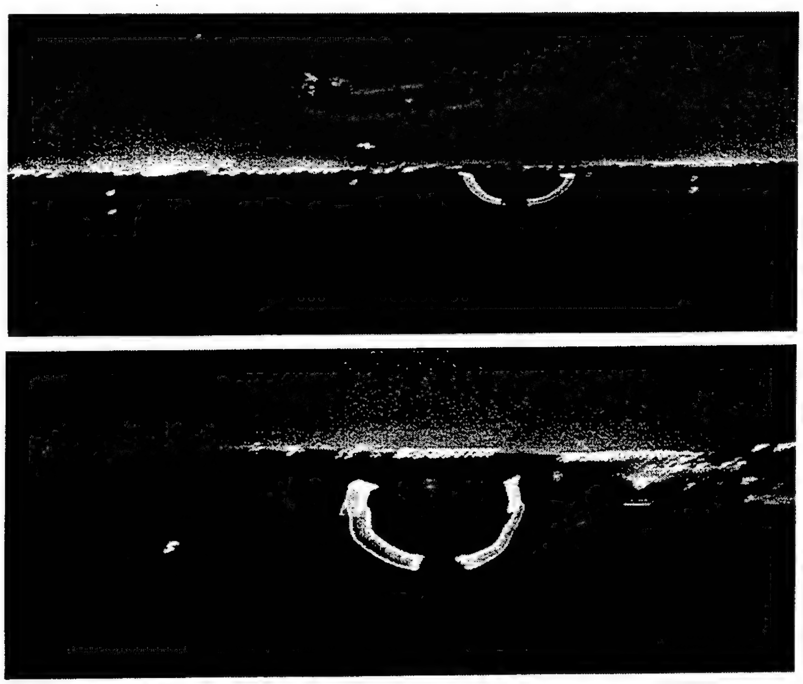

Figure 2: Two versions of the Move Down Signal.

Note the relationship between the upper limit of motion and the shoulder level of the trainee. In the upper photo of Figure 2, the upper limit of the arm movement is approximately shoulder level. In the lower photo, the trainee's arms have moved up past the plane of the shoulder and are ten to twenty degrees above it. While this small amount may seem trivial, the motion analysis systems need guidance on how to interpret movement of this nature.

The instructors unanimously commented that the hand signals should be given at a slow and even pace. We observed in the videotape recordings that there were inconsistent movement speeds in many cyclic movements that were not directly related to the particular movement. Cyclic movements may be thought of as those movements that have a repetitive component to them such as the "Land Here" signal. Some trainees would move their arms faster in the movement in the desired direction (i.e. raise arms faster than lowering them in the Move Up signal) while other trainees would reverse this trend. In the latter case, there seemed to be a correlation between overextension past the plane of the shoulder and speed of the retractive movement as one might expect.

While the pilot may be able to interpret what the LSE is intending to signal, the computer will be looking at what the profile is and attempting to interpret the data provided at that instant. Flexing the elbow(s) can provide some modifications to the movement profiles that may not be classifiable depending on the robustness of the pattern recognition module. Figure 3 illustrates this challenge by a time lapse photograph of the Move Up signal in which the trainee was bending his elbows on the downward stroke. The upward signal follows a nice clean arc while the downward movement is a little more complex. It appears that just after the adduction of the shoulder begins, there is an increase in elbow flexion. This movement produces the near-vertical drop in the wand location. As the LSE continues to lower his arms, he reverses the forearm movement by extending his arms thus closing the circle. There is little chance that the trainee was aware of this movement variation although the pilot could see it. This minor deviation from the "ideal" arcing signal did not appear to affect the safety of the evolution but does present a situational awareness challenge to the automated pattern recognition system (i.e. "How much elbow flexion should be tolerated and classified as an acceptable motion?"). One vexing portion of the motion analysis challenge is determining what motions are acceptable fleet habits, personal flourishes and the like and what movements are simply improperly done.

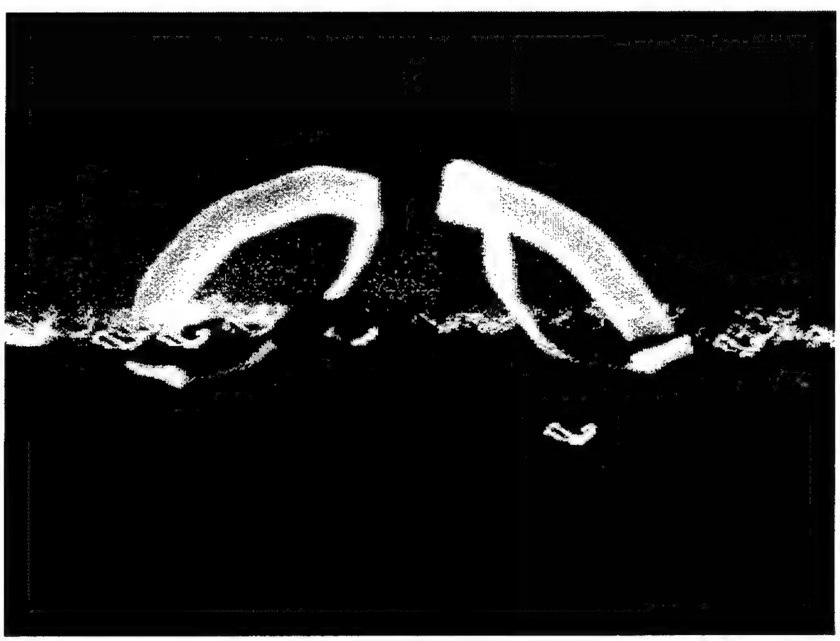

Figure 3: Example of common error (elbows bent).

Signal order and transitions

The frequency of each signal's occurrence may be used to prioritize what profiles need to be developed first. The raw data must be categorized by the type of training session (i.e. approach and departure, VERTREP, etc) to adequately develop an intelligent pattern recognition algorithm. Three pad sessions were observed during the site visits. The only day session was an approach and departure period that was the students' first introduction to pad operations. Two night VERTREP pad sessions were observed. All sessions were flown with a CH-46 helicopter although the day session was originally scheduled for a SH-60. It is possible to construct a sequence map of the signals to assist in the training of the pattern recognition algorithms. Since the entire evolution is dynamic, additional constraints are therefore placed on the recognition modules. Table 3 lists the number of each signals collected. We were unable to collect data on all of the signals described in NAVAIR 00-80T-113 as several are specifically related to engine start/shutdown and rotor engagement/disengagement.

Table 3: Hand signals recorded during the site visits.

Name	Code	Day samples	Night Samples
Clearing Turn	CT	6	21
Move Down	DN	6	24
Hold on ground	HLD	6	---
Hook Up Load	HUL		18
Hover	HVR	36	68
Land Here	LH		13
Land	LD	6	---
Move Back	MB	6	---
Move Forward	MF	5	17
Move Left	ML	5	7
Move Right	MR	5	8
Pedal Turn Left	PL	5	8
Pedal Turn Right	PR	5	1
Release Load	RL		16
Take Off	TO	6	23
Move Up	UP	6	18
Wave Off	WO		1

The first pad session is intended to introduce the student to the LSE's environment and gain some preliminary exposure to giving signals. The helicopter flies a standard approach pattern to a landing then departs when directed. The LSE trainee is permitted to issue several directional signals such as Move Left or Pedal Turn Right to gain the experience of what the appropriate response should be. Accordingly, most students will have the opportunity to bring the helicopter in and reposition it around the landing area. The pilots commented that they really try to work with the students in this session. Table 4 identifies the signals typically given in this session along with what the subsequent signal was.

Table 4: Approach and Departure (Day) Signals

H/S	CT	DN	HLD	HVR	LND	MB	MF	ML	MR	PL	PR	TO	UP
CT												6	
DN				4	2								
HLD													6
HVR	2	5			3	6	1	5	5	5	4		
LND			6										
MB				5	1								
MF				5									
ML				5									
MR				5									
PL				5									
PR				5									
UP	4			2									

The review shows that almost all trainees did comply with the guidance to follow a directional signal with a hover signal. This gives the helicopter time to stabilize its motion before the next signal is given. The one Move Back signal that was followed inappropriately with the Land signal represents a potentially hazardous situation especially on a smaller flight deck. It is difficult to determine if there was a rush to catch up with the operational pace or simple expediency in progressing from the Move Up signal to a clearing turn (4 of 6 samples) or to a hover (2 of 6 samples). The tendency to catch up with the speed of the evolution usually appears when the trainee drops the intermediate Hover signal. The purpose of this session is to gain experience giving signals. However, each student only receives about two minutes of contact time in this session. If the student is having difficulty with the proper situational awareness, they may not get any additional time as fuel load and the student load may not permit extra work to reinforce the concepts. The proposed VVAST device could provide more

extensive training to the LSE students at a fraction of the costs involved in the two hours of flight time.

The night training session is the trainee's first exposure to the VERTREP environment. Hence, a different standard set of approved signals are utilized. The night environment does present the students with their first exposure to signaling with the standard flashlight wands. One benefit to this is that in a very subtle means, the importance of proper hand position is emphasized as the student signals. In the day session, there was a minor tendency for some uncertain trainees to concentrate on the arm position and neglect the wrist angles. The use of the wands appeared to reduce that effect. VERTREP operations are different in character than the previous session in that the helicopter will not land while the student is signaling. Therefore, no Land signal is given while the Hook Up and Release Load signals are used predominantly. Table 5 reflects the signal frequency and subsequent signal trends observed in the two pad sessions.

Table 5: Night VERTREP Signal Sequences

	CT	DN	HUL	HVR	MF	ML	PL	RL	TO	UP	MR	PR	WO
CT									21				
DN			7	1				16					
HUL				18									
HVR	11	19	4		1	8*	1	1	2	16	5*		
LH					12							1	
MF		1		13			1				1		1
ML			7*	1									
PL	1			7									
RL	1			12			2				1		
MR				7*			1						
PR				1									
UP	8			5			3		2				

Data marked with an asterisk was recorded under slightly different circumstances and an explanation is in order. The VERTREP pattern has slight differences between the two schools which are primarily geographically based. The isolated location of the training pad at NAS Norfolk allows the helicopter to simply move or slide to one side between releasing the load and having the load hooked up. This is done entirely under LSE control. The proximity of the other landing pads at OLF Imperial Beach (seven pads are lined up side by side) does not permit this type of pattern without tower approval and no other traffic at the field. The helicopter flies a

normal pattern in between load drops and pick ups. The difference in patterns does not affect the quality of training other than to slightly modify which signals are given more frequently. The additional pattern time does cut into the amount of flight time available to the students. The VVAST device could provide some of this training in a cost effective manner. It must be pointed out that the complexity of the vertical replenishment operation requires some practical exposure to the process in a training environment for prudence and safety. The use of the VVAST device in VERTREP training would enable the students to train and practice the emergency situations that may occur and are impractical or unsafe to do in a live session. In this light, the VVAST device may substantially add to the depth of training resources available to the LSE Instructors.

A striking trend appears immediately in reviewing the Move Down signal sequences. In sixteen of the twenty four signals recorded, the Move Down signal was not followed by the hover signal as was discussed in the classes. The results are split between the Hook Up Load and the Release Load signals with the latter more prevalent. The answer to the appropriateness of these results lies in the determination of several related factors. Are the LSEs trained to understand that going from a Down signal to a Hook Up or Release Load signal in the VERTREP environment also has the double meaning of Hover or was the pilots' experience level obviating the need to give the hover signal? While the latter possibility may eliminate a small part of the learning experience in the live operations, the risks of blindly following incomplete or inappropriate hand signals are too great. If the latter possibility is the case, the pilots are doing exactly what they are supposed to for safety of flight. The CH-46 NATOPS Flight Manual clearly delineates a standard communication sequence between the aircrewman and the pilot during the VERTREP evolution. It is entirely possible that the intra-cockpit communication is obviating the need for the Hover signal to following the Move Down. It is not clear how many LSE students realize this communication is taking place and instead blithely proceed with the signals as if the helicopter's downward movement stops automatically. This may potentially be lead to a premature case of complacency. The ability of the VVAST device to allow the virtual helicopter to strike the flight deck if the downward movement is not arrested by a Hover signal may enable the instructors to proactively address the complacency.

The benefits of this type of training would include reinforced proper signaling techniques and improved situational awareness. What is important at this stage is to evaluate the data and determine the proper signal sequence with various errors included for this type of evolution. The same analysis will be required for any other live helicopter LSE training operations such as the winching session we were unable to observe. This data does provide several key issues that must be incorporated in the creation of an automated intelligent pattern recognition algorithm.

Anthropometric analysis

One significant noise source in the motion analysis problem is the different anthropometric sizes of the system users. Williams and Listner (1962) published a scaling algorithm for biomechanical measurements that provides a means of determining the approximate limb dimensions based on a subject's height and weight. It is our intention to incorporate the sizing algorithm into the initial prototype development to more aggressively test the system. The purpose of this section is to create a means of identifying the ranges of movements that the VVAST device may see from the user population. The amount of original signal available for the system to process is somewhat dependent on the physical size and dimensions of the individual LSE's arms. After reviewing the segmental link and length data presented by Williams and Listner (1962), we were somewhat concerned about the validity of the thirty to forty year old scaling algorithm. The average size of the cadavers that Williams and Listner report was 68.9 inches. This seems somewhat small in view of the increasing average heights of the younger population.

Winter (1990) presents several different algorithms for determining the biomechanical parameters for each segment. The most consistent scaling appears to come from the work of Dempster and was reported by various sources in the early 1970s. The segmental lengths are determined as a function of the subject's height. Segmental mass properties are a function of the subject's weight. We informally tested both scaling algorithms against several individuals at our facility and found the Dempster parameters were more representative than the Williams and Listner values. As a result of our experiences with both sets of parameters, we elected to use the Dempster values for trainee size scaling algorithms. The height related parameters are shown in Table 6.

Table 6: Segmental length data as a function of subject height.

Segment description	Multiply subject's height by x to get length
Top of head to shoulder	0.182
Shoulder width	0.259
Arm length vertical	0.188
Arm length horizontal	0.186
Forearm vertical	0.145
Forearm horizontal	0.146
Hand vertical and horizontal	0.108
Spine to lateral shoulder edge	0.129
Floor to acetabulum	0.530

Segment description	Multiply subject's height by x to get length
Floor to knee	0.285
Pelvic width (acetabulum to acetabulum)	0.191
Floor to top of shoulder	0.818
Acetabulum to shoulder	0.288

Segmental mass data may similarly be calculated by multiplication of the subject's weight by a constant as shown in Table 7.

Table 7: Segmental mass data as a function of subject weight

Segment	Mass factor	Proximal CM/L	Distal CM/L	Density
Hand	0.006	0.506	0.494	1.16
Forearm	0.016	0.430	0.570	1.13
Upper Arm	0.028	0.436	0.564	1.07
Total Arm	0.050	0.530	0.470	1.11
Foot	0.0145	0.50	0.50	1.10
Leg	0.0465	0.433	0.567	1.09
Thigh	0.100	0.433	0.567	1.05
Total Leg	0.161	0.447	0.553	1.06
Thorax	0.216	0.82	0.18	0.92
Abdomen	0.139	0.44	0.56	------
Pelvis	0.142	0.105	0.895	------
Trunk	0.497	0.500	0.50	1.03
Head and Neck	0.081	1.000	-------	1.11

It should be understood that these parameters are at best approximate as humans have a myriad of different shapes and sizes. In view of the screening that takes place in joining the military, we should be able to use these values with some higher degree of reliability in modeling the movements associated with each hand signal. The actual population that will use the proposed VVAST device comes in a wide variety of anthropometric shapes and sizes. This method can be used to simulate the input data generated by subjects at either end of the height and/or weight ranges.

The parameters listed in Table 6 enable a physiologically based determination of the required motion capture envelope size and location. For example, a nearly seventy inch wide window centered approximately fifty inches above the ground would be the minimum necessary to record the wand signals of a five foot tall LSE. A six foot, four inch LSE standing in the same spot would need a window approximately eighty five inches wide centered sixty two inches above the ground to capture the entire movements. These values are estimations based on the scaling factors described earlier and do not account for any bending or reaching by the user. The segmental weights in Table 7 are used to approximate the mass of each segment in the arm model.

MOTION CAPTURE SYSTEMS

Recent (last two years) biomechanical and virtual environment/virtual responsibility literature has been surveyed to determine the current, emerging and novel technologies in motion capture and analysis. There are four types of technologies used in current motion capture and analysis systems: optical, electromagnetic, acoustic and mechanical. Manufacturers of motion analysis systems in each general category were contacted and where possible, evaluations of the devices were conducted. The evaluation of the optimal motion capture system to be placed in an existing structure requires that the facility characteristics be as important in the decision criteria as the actual details of the new system. This philosophy prevents the purchase of a superlative system that does not work at the installation site for lack of a prior site evaluation and preparation. A detailed discussion of the facility characteristics is given in Technical Objective Five.

The completion of this objective includes work in two separate but related areas. Evaluation of the biomechanical movement profiles associated with the standard hand signals, common variations, sequences and typical errors is necessary to determine what the nature of the potential input signals. An evaluation of the current, emerging and novel motion analysis systems must include data from both site visits and the results of some internal simulations and testing. The selection criteria included stated latency, operating range, sensitivity, post processing capabilities, personal computer compatibility, technical appropriateness and platform related software and hardware requirements.

OPTICALLY BASED SYSTEMS

Optically based motion analysis systems can use passive reflecting or actively emitting light sources using infrared or visible light. The markers must be securely attached to the subject and visible to the camera(s) at all times to accurately capture the motion. The location of the markers must be consistent across all subjects if any automated type of analysis is to be used.

Peak Performance

The Motus System is Peak Performance's latest offering in a series of video based two and three dimensional motion capture systems. The manufacturer is oriented towards research in sports medicine and biomechanics. This has led to the incorporation of several modules that automatically determine limb segment accelerations and velocities using accepted biomechanical models developed at the University of Virginia. The majority of the modules are oriented toward creating a clinical type profile of the movement. Reflective markers and calibration poles are used by the six camera system to track the desired movement.

As with any optically based system, line of sight becomes a critical factor for accurate trajectory capture. Numerical interpolation routines are incorporated into the Motus software to fill in missing data. While the vendor is promising real time video acquisition and movement analysis, a company representative indicated that this capability was recently released and will ship more once some of the final bugs are worked out. The Motus system runs in the Microsoft Windows operating environment using a combination of proprietary hardware and software. In comparison to the other three systems selected for evaluation, the Motus system reflects the most current biomechanical movement analytical techniques as a result of the manufacturer's ten years in the field. Although the system advertises a real time video collection and analysis capability, the real time capability is not ready for release and will not be until the fourth quarter of 1996. The basic system includes an automatic calibration routine and several add on modules for miscellaneous clinical and motor control research protocols. A pan and tilt module is also offered to enable real time acquisition of the camera angle(s). The pitch and roll data is encoded and stored on the video tape. Proprietary units are required to capture and decode the camera angle data. It does appear that the Motus system would be an efficient means of initial data collection but the proprietary nature of the individual system suggests that little room would be left for subsequent signal processing to support the VVAST device. We have discussed the possibility of bringing a Motus system into our facility for a three to four day evaluation period. The number of components (cameras, tripods, modules, support cabling and master computer) and strict recalibration made this unfeasible. The base system cost is in the $75K range.

The manufacturer recently advised that they are still working on the real time data collection modules and were performing the initial tests with a four camera system in early September. It would appear that the fourth quarter release date may be optimistic from the tone of the discussion. We were able to obtain the optical specifications of the MOTUS system video cameras during our last conversation with the vendor. These dimensions may be superimposed on the proposed installation site drawing in technical objective five to determine if a four or six camera system configuration will allow the sufficient room for the LSE trainees to signal to the virtual helicopter. The anthropometric calculations are important in determining the effect of various trainee heights on the ability of the motion capture system to record the movements.

Optically based motion tracking systems rely on redundant cameras to reduce the problems associated with lost or missing marker trajectory data due to a blocked line of sight.

The alternative to redundant cameras is an off line numerical interpolation whose accuracy depends on the amount of missing data and the predictability of the movement. MOTUS system cameras are available with either a standard 8 mm lens or a wide angle 6 mm lens. The field of view (FOV) dimensions are referenced to a fifteen foot boresight distance along the camera axis. The standard lens will allow a field of view that is 43 degrees wide horizontally and 33.5 degrees wide vertically. The wide angle lens has a 58 degree field of view in the horizontal and a 45 degree field of view in the vertical.

The field of view for the camera may be thought of as a three dimensional cone expanding along the lens boresight line. Therefore, to take full advantage of the camera in a motion analysis system, the entire motion must occur within the FOV. In the case of the multiple camera redundancy constraints, the motion must occur in full continuous view of the minimum numbers of cameras required for a desired level of accuracy. Superimposition of the FOV cones from cameras placed at different angles enables the determination of the amount of room where the system will allow three or more camera coverage. We have included a depiction of the horizontal field of view cones for two possible four camera system configurations. It should be noted that these are strictly horizontal plane "bird's eye" views. The vertical FOV of the system is adjustable to the trainee height with some minor modifications but is constrained by the horizontal separation between cameras. Hence, the bird's eye view perspective will be most effective in system analysis and evaluation.

ELECTROMAGNETIC FIELD BASED SYSTEMS

Polhemus Fastrak and UltraTrak Pro Systems

There are two systems produced by Polhemus that utilize a proprietary electromagnetic field technology to obtain near real time three dimensional trajectory data. Two of the more recent system offerings are included as potential evaluation systems: (a) The Fastrak System and the newer (b) UltraTrak Pro System. Both systems are sensitive to metal objects within the sensing range but may provide a good start on the hand signal profile determination under both the stationary and moving protocols. Both systems do include extended range transmitters (optional on the former and integral on the latter) and CRT monitor noise rejection. However, the sensitivity of the electromagnetic field to metallic objects will limit this use of this device to the initial test and evaluation phases.

Fastrak System The Fastrak system is a four channel system with a sensing range in a non-metallic environment of 10 feet. This is approximately the magnetic field diameter and may be too small for the amount of space necessary for the LSE to move around in. The optional Long Ranger transmitter is reported to extend the tracking range up to three times according to the manufacturer. This may be a newer unit as we were unable to get any real performance stories from the local Polhemus representative as they are just beginning to test the transmitter device. We were told that there is some decrease in resolution with this transmitter although that may simply be the result of the spherical field expansion over distance. This system does allow four receivers but the maximum sampling frequency is limited to 30 Hz. The trajectory data is transferred to the computer through the RS-232 port. The base system cost is in the $7,000 range with the optional Long Ranger transmitter costing $3,500.

UltraTrakPro System The UltraTrakPro system is the latest offering from Polhemus that increases the number of simultaneously acquired channels possible, sampling frequency and effective range. This system includes proprietary hardware and software that will output the motion data to another computer through an Ethernet connection to increase data throughput. There may be up to 32 channels sampled at 60 Hz with this system with a slight decrease in accuracy and resolution. The decreased accuracy is not that substantial for the purposes of VVAST and may actually play in our favor as a sort of filter as the LSE moves around. The hardware unit is a rack mounted Pentium computer with extended cables connecting the transmitter and receivers. The base price on a unit capable of sensing 8 channels at 60 Hz is $23,500. After a discussion with the local sales representative, it appears that the base unit is not available without additional clinical analysis software developed by the sales representative unless one contacts the manufacturer directly.

The possible installation sites at both locations contain a significant number of metallic objects that are used as examples in the training program. The use of this technology in the proposed spaces at both sites would require removal of the ferrous metallic objects that are critical to the curriculum from the immediate area. As one goal of the proposed device is to blend into the existing facilities, the potential cost of any modifications necessary to incorporate the electromagnetic tracking into this device may outweigh the benefits.

After observing the amount of walking around that the LSE trainees do during the live flight operation pad sessions, we contacted the Phoenix area manufacturer's representative for the Polhemus devices to discuss the Long Ranger™ extended range transmitter characteristics in an older building. The discussion yielded a new requirement in that they (the manufacturer or the representative who writes custom software for use with the Polhemus devices) would have to develop a custom electromagnetic field mapping algorithm and integrate it into the motion analysis software if the proposed room contains any substantial amount of metal or electrical wiring in the wall(s). The facility site inspections revealed a reasonable amount of metallic objects present in the room that are either fixtures (radiator piping or electrical conduit) or furniture (rack of lockers, desks, tables). It is somewhat likely that the walls and floors of this older structure do contain steel support beams. Thus, an electromagnetic tracker may have some difficulty with the amount of surrounding metal. This presents a significant problem to the use of this type of motion capture system in that the field calibration could be challenging to develop and maintain.

Assume for the moment that the field distortion is insignificant. The thirty to sixty inch work volume for accurate sensing is not large enough to contain the hand signals of a medium sized LSE trainee if any lateral movement (i.e. steps) occurs. The space requirements are too restrictive for this technology to warrant further investigation for this application

Intersense Technologies

This manufacturer has recently changed names to "Intersense" and moved into different facilities since the VRAIS '96 conference advertisements. The vendor's core product is a three degree of freedom (DOF) sourceless tracker that provides pitch, roll and yaw information. The six degree of freedom unit incorporates an ultrasonic position tracking system to get absolute location. They are developing and marketing an inertial acceleration sensor that may be coupled with a position sensor of the user's choice. The sensor is composed of three solid state technologies: (1) three orthogonally mounted miniature gyroscopes; (2) a two axis fluid inclinometer and (3) a single flux gate compass. The inclinometer and the flux gate compass are used to correct for gyroscopic drift by fusing all outputs together in the onboard electronics module. The technical specifications, small physical dimensions, power requirements and compatibility with the PC environment make this technology an exciting opportunity.

While the sensor provides high quality acceleration information from the inertial system, there is some difficulty in also recording position information. This has been addressed by the manufacturer by enabling the incorporation of this technology with an ultrasonic tracking system. Position data is obtained by placing small ultrasonic transmitters on the object to be tracked and using ceiling mounted receivers to collect the data. A coded infrared (IR) signal is used to activate the transmitter.

The sampling frequency for this device may be as high as 500 Hz depending on the installation placing it far above previously described technologies. The software does allow some predictive work to reduce the data overhead and can compensate for short gaps in the ultrasonic line of sight. The use of the coded IR signal to activate the transmitter reduces the noise reflection problems inherent in an acoustic tracking system somewhat. It is unclear how ambient ultrasonic interference will affect the position tracking system. The line of sight issues are more critical for the 6 DOF system according to the Marketing Director who stated that their system doesn't handle a loss of sight well. He did indicate that Intersense was about to begin work on incorporating the inverse kinematics into their current software package but hadn't gone too far in that direction. The base system which does not include an ultrasonic position tracker lists for approximately $7,000. The inclusion of the position tracking devices raises the costs to approximately $11,000.

The product evaluation originally scheduled early in this project was rescheduled several times due to manufacturing related delays. The manufacturer was experiencing difficulty in debugging the device's input / output (I/O) card initially. The demonstration units that were scheduled for our evaluations in both August and September were then sold to other customers. The next production run was in September and they had hoped the demonstration unit would have come from that run. After returning from the Norfolk site visit, we contacted Intersense to inquire about the status of the demonstration unit we had been discussing. The Marketing Director informed us that all units from the September production run had been sold and that a demonstration unit would not be available until late October or November. It was also discussed that a purchase order would not move us up further in the queue. It appears doubtful that one will become available in time in either the three or six degree of freedom models to include an evaluation of the Intersense sensors in this study.

Precision Navigation

This manufacturer advertises a magnetometer based device that extends the motion tracking capabilities over current inertial based sensors. The product is based on high performance compass technology and is composed of a 3 axis magnetic field sensor and a 2 axis tilt sensor. It uses the earth's magnetic and gravitational fields to detect orientation and may be contained in a small head mounted unit. There are no required transmitter, restricted line of sight or narrow cone of space limitations. Motion data is transferred to a personal computer via the standard RS- 232 interface. The vendor also states that the device performance may be calibrated in weak or strong electromagnetic fields. The TCM-2 electronic compass module does not use mechanical gimbaling to sense the level of the transducer rather, an electrical level detection approach is taken with a fluid inclinometer. The unit is available in three different ranges: +/- 20 degrees ($699); +/- 50 degrees ($799) and +/- 80 degrees ($1199) pitch and roll. The box size on this unit is approximately 2 inches x 2.5 inches x 1.8 inches.

The stated accuracies of each device range are less than 1 degree. Each TCM-2 also includes both software and hardware iron distortion correction algorithms to enable use of the device in environments with nearby ferrous metals or electrical currents which may affect the device's accuracy. The maximum sampling frequency appears to be 30 Hz. The latency of the signal is approximately 100 milliseconds (ms) on the normal mode and 80 ms on the fast data acquisition mode.

One additional sourceless tracking product is offered by this vendor. The Wayfinder VR is a companion or similar product to the TCM-2. When it was tested by the manufacturer it was found not to be as accurate as the TCM-2 module. Therefore, the company reduced the price on the unit and has stated that they are not trying to push the Wayfinder VR in the market. The magnetometers in both devices sense the earth's magnetic field provided that there are no large electromagnetic sources nearby. As long as the trackers do not get too close to each other, the company representative we spoke with did not feel that there would be a problem. The representative was not able to guess what the "too close" distance was.

One demo program (TCM2.EXE) is shipped with the product. The vendor does not provide any substantial software support for further interface development. The device will function with a standard terminal emulation such as Telex or Procomm to control the device. There are no circuit boards or any other peripheral requirements with this device since the primary interface is through the RS-232 port. The device samples the sensors to determine if any changes have occurred the transmits the output data in ASCII format.

Although the main transducers are magnetic in origin, tilt is measured in pitch and roll through a bi-axial fluid inclinometer. The tilt sensor is an acknowledged problem in that acceleration is misinterpreted as tilt. Acceleration of the inclinometer results in the electrolytic fluid being forced against the side of its bubble. The end result of this is an erroneous pitch and/or roll indication. A review of the product information sheet does provide a compensation equation to estimate the error induced by known acceleration forces. The amount of error is also sensitive to the location of the TCM-2 within the Earth's magnetic field and as expected, nearly ferrous objects. The fluid sensitivity to acceleration is one of the major limitations to this

device's application to this project.

The TCM-2 module, and its less accurate sibling, the Wayfinder VR, are marketed with different tilt limits as discussed earlier. The tilt parameters are a significant source of error if the limits are exceeded. The amount of heading error induced by exceeding the tilt limit(s) is a function of the excursion magnitude and the location of the sensor within the earth's magnetic field.

The natural frequency of the fluid inclinometer's liquid is approximately 20 Hz. In this range of vibration, it is likely that erroneous heading readings will occur. While this frequency range is above what the anticipated vibratory inputs are, it is possible that some component of the environment or the VVAST device may generate noise in that range. Air handling systems or other mechanical devices such as moving platforms may produce vibrations in this range. Potential noise generating components within the VVAST simulator include the proposed air handling or low frequency sound generation systems. Fluid inclinometers by design can be very shock sensitive and rough handling or dropping the device accidentally may inactivate it.

All issues considered, there were some promising trends with this device that merited further examination. While there were several interesting points to this device, the combination of acceleration sensitivity and pitch and roll limits severely restricts the potential use in the VVAST system. There is a 100 ms latency before a motion is sensed that could present an unacceptable delay in the signal processing since several of the hand signals are short duration motions lasting a second or two. The limitations of this sensor eliminated it from further consideration due to the restrictions placed on the operating envelope.

MECHANICAL ARM TRACKING SYSTEMS

Shooting Star Technologies

The ADL-1 mechanical tracker has been on the simulation market for the past five years and consists of a three linked segment, six degree of freedom mechanical tracking device. Originally designed as a head tracking device with a 36 inch horizontal and 18 inch vertical range, the ADL-1 offers extremely low latency and low noise motion capture technology. This device can transmit three dimensional position, pitch, roll and yaw data to the host computer through the RS-232 port in one of three modes: Demand, Incremental and Continuous. The maximum sampling frequency is approximately 700 Hz with a latency of less than 2 milliseconds. The limited work volume may provide some problems with this device due to anthropometric considerations.

This device offers several attractive features in terms of latency and data acquisition speed but is about to be removed from the market due to chronically low sales according to the manufacturer. The complexity of the hand signals given by the LSE and the intentional translational movement to improve pilot-LSE visibility may combine to provide an insurmountable wall to this device. The hand signals where one arm crosses over another (i.e. Land, Release Load, Cut Cable, etc.) may routinely create a situation where the linkages attached to each trainee's arms may collide. This may be addressed with proper positioning of the source linkages. However, this could prove to be a significant implementation challenge.

We are going to explore the potential of mechanical tracking with a mock up linkage to see if it is possible to arrange the linkages to avoid conflict. This series of tests will determine if mechanical tracking arms are feasible.

FARO Technologies

This manufacturer recently offers a mechanical arm system that is primarily oriented toward three dimensional digitization of objects. We contacted FARO to evaluate the potential of their product, which comes in three different lengths larger than the ADL-1 unit, as a potential mechanical arm system. The unit comes in several configurations with the distribution of the degrees of freedom per joint in the linked segment arm up to the user initially. Two different probes may be attached to the end of the arm depending on the surface or object to be measured. Data may be sent to the computer through the RS-232 port continuously or on demand by clicking a button attached to the probe. Custom software is available to assist in the digitization of the objects under study. The weight of the linked segments is between six and twelve pounds depending on the work volume desired.

Mechanical Arm Technology Evaluation

We created two linked segment models that had adjustable lengths and weights. While the mock up linkages were somewhat primitive, what we were looking for was any collisions that might occur during the course of the standard hand signals we had observed during the pad session. The majority of the directional signals did not produce a conflict between linkages. The Land signal (given following the Move Down signal) did produce a collision between links as both wrists are internally rotated and crossed to create the palm down, crossed arms signal. The weight of the arms was very distracting as the movement speed increased. We considered the option of mounting the segment base on the ceiling to give more room but could not work out an acceptable arrangement that would allow a full range of trainee heights and arms spans without a major modification to the proposed installation spaces. LSE trainees must learn to move laterally to maintain continuous visibility with the pilot. This additional constraint severely limits the application of mechanical arm sensors in the VVAST device. Further investigation into mechanical arm based tracking technology for this application is not warranted at the present time.

EMERGING TECHNOLOGIES

IMI-PCB Tri-axial accelerometers

In view of the potential for a simplified sensor device using solid state tri-axial accelerometers, we have contacted several manufacturers including Endevco, Entran and IMI-PCB to discuss their products. All three were willing to provide technical specifications with the latter also willing to provide a couple of samples for a no charge trial and evaluation. In reviewing the product literature, all of the products require a +18 to 24 Vdc supply voltage. This is typically more than most computer based data acquisition and process control boards provide and therefore some additional power supply would be necessary. Endevco's units require a separate power supply (115 Vac) and conditioning module. The Entran and IMI-PCB devices

did not require the additional box and were available in whatever wire configuration (e.g. BNC, RJ-11, blunt ends, etc.) the customer requested. The supply voltage could come from a battery pack depending on the user's needs. The applications engineers and technicians we spoke suggest that their products are only vibration sensors but the literature would suggest alternative uses.

We arranged for a 30 day trial with this vendor's solid state tri-axial accelerometer Model 329 unit during the month of September. The unit is a small device shaped like a solid triangle approximately 0.5 inches thick. A MIL-SPEC connector is used to attach the leads to the sensor. A shielded four conductor wire leads to the data logging device. The excitation voltage and current requirements of 24 VDC and 4 mA are typically supplied by a regulated power supply. The manufacturer recommends their own unit with the qualification that most industrial standard power supplies will work.

The physical dimensions of the accelerometer are approximately 1.5 x 1.5 x 0.5 inches. Each axis of acceleration is specified clearly on the exterior of the device. In order to mount the device per the manufacturer's instructions, the surface must be ground to a smoothness of 0.0016 mm or better and be flat. The surface preparation requirements also included the precise alignment of the etched lines with the desired direction of movement sensing. The device is also sensitive to the amount of torque applied during the installation.

The mounting requirements really put a crimp in the device's evaluation. It was our hope to mount the accelerometer in such a manner that we could keep the orientation of the axes fairly consistent. Once the starting position was identified (e.g. in the "Land Here" position with the arms extended vertically and held still) to the computer, we hoped to record the signals continuously from that point to drive the simulation. It was hoped that even if there was a small amount of rotation as the student rotated the sensor wand in their hand, we would still be able to identify the acceleration patterns. This approach was unsuccessful in our own lab tests and in reconstructing movements from the two videotaped pad training sessions. There is a substantial amount of wrist movement in the majority of the NATOPS standard helicopter signals. The inclusion of personal flourishes and "fleet" signals introduces an overwhelming amount of noise into the potential signals.

The Move Up signal, for example, begins with the arms extended laterally and the palms up. As the arms are abducted, the relative position and angle of the hand relative to the forearm and arm remains constant. When the LSE is holding a flashlight wand, the biomechanics of the movement change. As the wrist is held at a particular angle to keep the wand horizontal (an angle that in itself has a tremendous variation between individuals), there is a strong tendency to induce an internal rotation of the humerus and wrist during the arm's upward movement. The result is that the original axes are rotated nearly 90 degrees about two of the three axes. Thus, the majority of the movement's accelerations will be transferred from one combination of axes to another. The difficult part of this feature is that this is a subtle movement that the trainees (and even most instructors) will not be aware of because there are so many other more critical factors in the movement. The subtle rotational movement also does not appear to affect the pilot's understanding of the signal or the operational pace of the evolution.

We considered mounting the accelerometer on a wrist band to minimize the effects of the trainee's grip on the sensor wand. The amount of noise generated by subtle wrist movements such as one or two axis wrist flips to emphasize a hover signal or a circular movement on the Take Off signal was substantial. The videotapes clearly showed several different types of wrist movements used by students and instructors as either attention getting devices, signal separation devices (i.e. "I'm now signaling a hover") or personal flourishes (i.e. variations on the salute after the take off signal).

Connectix QuickCam

The Connectix Corporation offers a small charge coupled device (CCD) camera that attaches to the personal computer through the parallel port. The unit is intended for both the videoconferencing and video capture markets. Color and black and white models area available for use with IBM compatible computers. The operating software writes the camera images directly to the hard disk then updates the screen. This produces a jerkiness in the screen display to any rapid movements that decreases as the processor speed increases. We ran a short series of tests capturing hand signals with a QuickCam unit attached to a Pentium 75 MHZ computer with 16 MB of RAM. The camera was in the monitoring mode with a window size of 160 x 120 pixels and no images were saved to disk in order to characterize the throughput. There was a noticeably uneven character to the screen updates as the speed of the hand signals increased. While an interesting new product, the display updates were sufficiently slow to remove this product from further consideration at this time. Future models may be worth an evaluation.

NOVEL TECHNOLOGIES

A few words are necessary about the definition of the novel technologies. The evaluations already presented describe several leading motion capture products that are very good in what they are designed for. However, these same products have features that do not support their use in this project for various technical reasons. The decision not to implement a particular product in the VVAST device is based on a combination of technical, operational, implementation and administrative criteria. The Novel Technologies section attempts to elaborate on some of the concepts and potential new means of collecting the LSE trainee's hand signals for use in controlling the display.

The LSE classes have an average of twenty students and only a couple hours are available for each pad session. If the VVAST device is to be integrated into the current operations, it must not require more than a few seconds of set up time between students. This presents a stringent requirement to almost all motion capture sensors in that the transducers must be capable of rapid and consistent placement. Since this is a training application, the transducers must be mechanically tough enough to survive the expected rough handling and yet not detract from the training experience. The placement of sensors with cables running back to the computer is going to be a distraction to the students who may have little interest in computer based data acquisition and the various features of the experience such as wearing cables taped to one's clothes. The "guinea pig" atmosphere would substantially detract from the training provided by the VVAST device. Currently, there is only thirty to sixty seconds to place a new student into the signaling position. An significant increase in this time would present a near insurmountable cultural barrier to the device's acceptance. Therefore, it is important that the motion capture technology be nearly invisible to the trainees and require little or no instructor intervention between students.

In order to meet this requirement, we are developing two novel approaches to motion capture that, if successful, will bring certain intangible factors to the simulation that will help create that illusive sense of presence in the virtual environment. These ideas resulted from discussions occurring as the data from the site visits was analyzed. While some may not be as technologically advanced as some of the commercial products, they are more advanced in terms of applicability to desires expressed by fleet personnel and available technical support capabilities at each potential location. In view of the novel approaches, the full scale development of these technologies may not occur entirely within the Phase I effort. However, we are developing a proof of concept simulator that will utilize the "Man in the Loop" approach and will be complete within the Phase I effort. The motion capture and pattern recognition modules represent the front end of a complex simulation. The object oriented approach we have taken in the prototype design will allow the incorporation of the novel technologies with the other system components.

PC-Video

The multi-purpose classroom at each HCO/LSE School has an approximate free working area available of 17 feet by 13 feet that is limited by existing construction necessary to other tasks. The four camera system may be used to evaluate the facility requirements. The evaluation must strike a balance between room modifications, lost floor space due to equipment foot print and potential range of trainee arm motion. The optimal arrangement is to have the cameras separated by 90 degrees to maximize the multiple camera field of view window dimensions. The two dimensional nature of optical recording using a single camera also requires that the majority of the desired motion take place in the plane perpendicular to the bore sight line. Installation of a four camera system into the proposed room would yield a roughly circular window approximately 6.5 feet in diameter to capture the LSE's movement given the existing constraints in the horizontal plane. While the exact placement of the cameras may yield a slightly larger window, this is a reasonable figure for evaluation purposes in terms of anthropometry.

After inspecting the proposed installation sites, it was determined that a multiple camera optical tracking system would not be applicable for several facility related reasons. Aside from the technical constraints of real time motion capture and analysis, the installation and maintenance of a six camera system in the proposed sites could be prohibitively expensive and space limited. Although the room's black painted walls would be supportive of the optical marker tracking, the multiple use nature of the room (the HCO training console occupies a 4' by 11' space along the east wall, storage lockers occupy a six foot section of the north wall) substantially reduces the amount of available space a camera system that would have a wide enough field of view to allow the trainee to move four to five small steps in any direction.

Multiple camera motion capture systems had been looked at previously in the investigation and found unsuitable for this application due to the field of view (FOV) requirements necessary to maintain full marker visibility in at least two cameras. The motion capture systems are oriented toward near real time collection of clinical movement data. We had been approaching the challenge of LSE signal collection from the same view point. The site visits clearly illustrated the physical distances involved in the LSE-Pilot communication. While there is some three dimensional perception of the signals at typical distances, the majority of the

signals are two dimensional movements. To that end, we have been looking at the possibility of using a single commercial video camera with average resolution as the input device to a computer motion capture system.

Video capture boards are a relatively new component in that any source video can be compressed and stored directly on the hard drive. The stored data is quite large and some type of hardware and/or software compression must be used to avoid overwhelming the available space on the hard disk. The boards may also be used to simply display video such as television on the screen while the user works in other software applications. The concept here is to use a commercial off the shelf (COTS) video acquisition card and a commercially available video camera to display the movements associated with the LSE trainee in a small window on the monitor. A second transparent window is placed over the top of the video window that is used for the actual data acquisition. The second window is subdivided into regular grids of a size based on the pixel size of the window, the camera resolution and the range of each movement. In place of reflective markers placed on the LSE's hands, we thought that the use of standard issue flashlight wands would act as ideal active light sources. If the brightness of the room lights is going to be lowered to help the display device, this would only serve to enhance the contrast between the active light sources (i.e. the wands) and the background. The video camera is then placed such that the nearly 45 degree FOV is centered on the LSE's neck and that the entire vertical reach (with wands in hands) is visible in the vertical FOV.

The actual signals are tracked from the grid squares that the light appears in over a short time period (e.g. two to three seconds). The time based data is then used by the pattern recognition module to interpret the signal. The lower resolution of the COTS video camera and a larger grid size may be optimized to filter out any of the small oscillatory movements that may produce significant amounts of noise in higher speed motion capture systems. We have already acquired two Navy flight deck wand flashlights from a local police supply store for this series of tests. The use of the standard wands by the students in this approach eliminates any distractions or delays induced by sensor and cable placement. There is an additional advantage in that the use of a COTS video camera will help reduce the cost and increase the portability of the VVAST device.

Issues that need to be addressed include system resource usage in the different video display modes, window size and color depth, camera and screen pixel resolution, video camera frame rate, sampling frequency, grid size and data compression rate. The development of this technology will proceed concurrently with the development of the other modules but at a slower pace. The differences between analog video from the camera and digital video from the computer can present a significant technical challenge to the combined display. While the majority of the video data processing can be off loaded to specially designed plug in video cards, the imminent implementation of the IEEE 1394 digital video standard (also known as "FireWire") may eliminate this problem while improving the video resolution. Firewire is an all digital video format that may be transmitted directly into the computer. The concept here is to have the video from the LSE displayed in a window no larger than one quarter of the screen size to minimize the system resource usage. The virtual helicopter display will be in a window filling the top half of the screen while the instructor's control panel would occupy the remaining quarter of monitor screen real estate.

The continuous sampling and updating of the three windows provides a significant technical challenge to the single processor personal computer environment. The video capture card may provide a resource for diverting some of the calculations from the main central processing unit. Full operational capability of this system may require the use of a multiple processor or parallel processing environment to meet the computational requirements. Initial reports are just beginning to appear on high end personal computer workstations with multiple Pentium™ processors. This is a new entry into a hardware area that has been historically dominated by UNIX workstations and developers are still learning how to work with the environment. Current leading edge video capture cards such as FAST Electronic's AV Master do a superb job processing video and audio simultaneously but are extremely expensive in terms of system memory usage. Initial testing in our laboratory indicated that the resource usage was severe enough to prevent multiple applications from running at the same time. While initial operational capability of this video technology within the Phase I effort would be ideal, it is not required to produce the proof of concept prototype. The object oriented approach allows any type of motion capture system to be used as long as standard outputs are fed to downstream graphics modules. This technology may not be on line until the Phase II effort.

Artificial Retinas

A recent news release from Mitsubishi's Electronics Research Laboratories announced the development of a gesture controlled user interface that is based on a proprietary artificial retina integrated circuit. The device is targeted toward the personal computer gaming market and contains a two dimensional array of variable photosensitive cells (32 x 32 cells) as the front end. The sensitivity of each cell is controlled on the chip and is a factor in the input matrix calculations. The gesture recognition algorithms use the sensitivity matrix and the actual inputs from the photosensitive cells in a matrix multiplication process to determine the gesture presented to the computer. Initial results of this unit have been promising although the last published report (October, 1996) indicated that the artificial retina unit has only been tested with hand gestures (closed or open hand and different angular orientations) against a dark background. We contacted the local Mistubishi representative who stated that because this product is not yet ready for release, the manufacturer is being extremely careful in who they are making the product specifications and prototypes available to at this time. This device may become easier to evaluate later in 1997 after more development.

Radio Frequency (RF) Tracking

A second novel concept for unencumbered motion tracking is being pursued as a result of the same discussion. This concept may be described as a wireless system similar to computer based personnel locating systems. The initial system design consists of small, extremely low powered transmitters mounted within the operating flashlight wands that are tracked by passive radio direction finding (DF) units. Aside from the military and public safety uses of direction finding gear to locate hostile or emergency transmitters, there is a growing segment of the amateur radio community that uses small, often home made DF equipment to find a transmitter hidden by a member of the group. The practice is known colloquially as "foxhunting" and is similar to the combination of an orienteering meet and a road rally. Several small DF units are available for frequencies ranging from low VHF to over 1000 MHZ. These units may operate on

different principles such as the Doppler shift, phase and/or amplitude comparison and are sensitive to antenna design.

There are several challenges in radio direction finding including reflection of the desired signal, multi-path reception and interference from nearby frequencies. The ham radio direction finding industry is more of a collection of hobbyists than a full fledged industry. Most of the interest in the amateur market is in the Very High Frequency (VHF) bands that border most civilian air traffic control and public safety radio channels. The revolution underway in the higher frequency bands with the explosive growth of cellular phones, wireless computer networks and the developing personal communication services is opening up new frequency bands for commercial and private operators. Although licenses are still required to transmit legally on most frequencies, there are several bands that the Federal Communications Commission does not require a low power transmitter to be licensed.

The increasing use of the electromagnetic spectrum is starting to crowd the previously sparse airwaves with multiple transmitters. Radio signals are more like a Gaussian distribution "bell curve" about the center frequency than a spike directly over the desired channel. Therefore, there is going to be some interference from transmitters on nearby frequencies. The selection of the proper frequency range for this type of system to operate in will take more research. Once the target band is identified, it should be possible to determine what measures can be taken to track an extremely low powered signal close to the receiving antenna systems. This includes methods of dealing with interference from nearby transmitters, harmonic rejection, transmitter identification, reflection, signal polarization and multi-path reception. An additional area to investigate will be the desired frequency's behavior in tissue. This is not to open up the electromagnetic fields in biological tissues debate but a simpler issue of signal transmission through tissue such that reception at an antenna on the opposite side of the body is possible. The answer to this question would help define the receiving antenna placement window.

Frequency selection is only part of the technical challenge. The types of signal modulation and polarization are very critical. Spread spectrum (SS) technology is a recent development that is less sensitive of interference and multi-path reception as it spreads the center frequency out over a wider range than the classic narrow band signal. This feature forces the use of SS into the higher frequency range. As the signal encompasses more frequencies than conventional transmitters, the rejection of interference or jamming becomes more critical. Wide and local area computer networks are starting to explore the use of spread spectrum technology to improve connectivity. The developing personal communication services field presents additional possibilities for wireless communication.

One entry has been made into the use of RF technology into the human motion capture system arena but the majority of the advertisement was based on the Internet. What system performance data has been presented has been less than complete and significant technical issues were unanswered. The device appeared to be mainly theoretical in that the performance data appeared to be based on a point source within a non-reflecting three dimensional space yet the photographs illustrating the device's function were taken in a standard classroom with multiple metal and wood tables. Furthermore, antenna patterns are not as clean as a point source radiator.

This is a novel idea that is under development and will not be operational within the Phase I effort due to the amount of research that must take place. There is a substantial benefit in the concept when it comes to fruition in the simplification of the motion capture system. The LSE hand signals are a collection of standardized, large magnitude movements that are beset with an overwhelming range of minor variations, flourishes and common errors that no database can store all possibilities. Therefore, some method of data input filtering is necessary to make the system manageable. Assume for the moment that the ideal horizontal and vertical direction finding antennas exist and as part of the system are placed in front of the LSE at shoulder height. The bearings from the DF antennas would provide a standard digital input which may be used to develop evaluation criteria to the pattern recognition module. Clearly, this concept is still early in the development phase and many technical challenges remain. If this does prove successful, there is a substantial market for this technology in the multi-user simulation arena.

Man in the machine tracking

The operational requirement placed on the LSE instructors at both schools to provide LSE training at fleet locations away from the school's location generated considerable discussion on the portability of the VVAST device in support of this tasking. The integration of Naval Reserve Force assets and personnel to support the active duty fleet has been successful in several ways. If the VVAST device were to be used to support the mobile training team concept, there has to be a version or inherent capability of the device available that does not have any detailed facility support requirements yet provides a consistent level of training regardless of location. To that end, we have been exploring the potential of using the instructor at the keyboard to visually control the response of the helicopter through keyboard commands. The twelve function keys (F1-F12) located on the standard AT-compatible keyboard may be defined to suit the developer's needs. Although certain key combinations have standard behaviors (i.e. Alt + F4 to close an application), the use of the Shift and Control keys opens up nearly thirty possible programmable key locations.

An argument can be made that this is an older style, game style approach to the simulation and therefore further investigation of this approach may not be warranted. It must be remembered that there is no one optimal path to knowledge and that different instructors have different methods of communicating the material. This approach enables the instructors to break down a simulated approach in a step by step fashion to emphasize different points. This is currently done using stick mounted models and a cooperative imagination. The use of the keyboard control approach refines an existing method of teaching that allows the instructors to present different video and audio situations to the trainees. The combination of this feature with user selectable digital video and interactive simulations presents a very powerful tool for the LSE instructors.

The initialization phase involves setting several parameters that are used by the program to determine the time course of the simulation. This includes the helicopter's range, bearing and altitude, flight deck wind direction and speed and the deck status beacons. Eventually, this phase will include the weather conditions, virtual pilot experience level, deck motion and any pre-existing hazardous or emergency conditions. Administrative information such as the trainee's name, rate, SSN or command could be entered at this time. At the end of the initialization phase,

the operational simulation is started.

The operational phase begins with the helicopter approaching from a distance and ends when the Stop command is given. It is during this phase that the trainee signals to the virtual helicopter. The instructor then acts as both the pilot and the instructor and enters the proper code into the system once the trainee has given a proper signal. If the trainee's signal is unacceptable, the instructor does not enter the signal code and may pause the system to discuss the correct signal. This allows the trainee to receive immediate feedback on their performance. In contrast, the pilot flying the real helicopter is not going to put himself/herself at risk because the LSE trainee was giving inappropriate signals. Similarly, the instructor does not have the ability to stop the training session as required to correct and reinforce the proper signaling procedures. This is usually left for the standard, catch-all debrief at the end of the pad session (e.g. "Some of you did good. Some of you did bad. etc."). The VVAST device enables the instructor to pause the simulation when necessary to emphasize the proper signaling protocols. Using a programmed flight sequence which includes 3D, sound and wind elements provides an excellent rehearsal opportunity for the trainee to practice signaling while allowing instructor feedback via a radio transmitter and receiver in the trainee helmet. This configuration also meets the goals of the PQS system in that the trainee must demonstrate the skills correctly before a qualified instructor to complete a watch station.

Feasibility The implementation of the proposed VVAST device would have been difficult at best even a few years ago. Computer hardware and software are increasingly faster and more powerful. Notebook computers are approaching the computational power formerly found in high end UNIX workstations. This trend will continue for the foreseeable future and is capitalized upon in the VVAST device. The widespread popularity of personal computers (PC) and the associated graphical user interface has created an environment where many potential users are familiar with and can intuitively operate a pointing device (i.e. mouse, trackball or joystick). The new generation of rapid application development tools enables the developer to design and implement a low overhead graphical interface where a significant portion of the standard input data may be entered with the mouse. It is clear that a well designed interface that incorporates accepted pointing device input controls significantly reduces the user's learning curve and increases the acceptance factor.

The implementation of the prototype VVAST device is certainly possible within the personal computer environment. The use of a higher end workstation may be necessary to reach the processing power required by an automated hand signal recognition system but this remains to be seen. Advances in multi-processor personal computer technology may obviate this last statement. The portability criteria is met with the prototype design in the PC environment as powerful notebook computers are readily available and are about the size of the average aircraft NATOPS Flight Manual.

Advantages The benefits of developing a software based training application that capitalizes on standard interface and processing protocols cannot be overstated. As long as the standards (some in effect, some emerging) are complied with, the choice of the hardware platform is almost irrelevant. This statement must be qualified because this is an ideal goal that many workers are aiming toward. Software applications developed for one operating system are being ported to

other environments to increase the customer base. The development and implementation of the VVAST device as a software based system will substantially enhance the application's flexibility. The future growth potential is also enhanced as software upgrades are relatively inexpensive in comparison to proprietary hardware modifications. It is conceivable that versions of the VVAST device could be released in both the workstation and PC environments to support both fixed site and mobile LSE training team operations. While the underlying program may have some differences, the user interface would remain the same thus allowing consistent training to be provided anywhere.

Disadvantages The primary disadvantage with the "Man in the Loop" approach is the amount of training required for the instructor to become proficient in the device's operation. Secondary disadvantages include cost of associated supporting hardware and software. The use of standard graphical user interface conventions and a well designed, intuitive program structure can substantially reduce the time necessary to develop proficiency.

Data Collection Methods

It is assumed for the purposes of this discussion that the user instructors are already expert LSEs. The use of standard graphical user interface conventions and a well designed intuitive program design can substantially reduce the time necessary to develop proficiency. An example best illustrates the point. The proposed VVAST device has the capability of reproducing a multitude of training scenarios. If the hand signals commonly used in a particular evolution are assigned to specific function keys or screen locations, the instructor need only familiarize themselves with the arrangement. Once the schema is learned, the operating process is very straightforward allowing the instructor to focus on the training task instead of system operation. Table 8 illustrates one possible schema using the function keys. The key assignments shown were determined from observations made during the site visits on the frequency of usage and what followed a given signal.

Table 8: One possible function key signal assignment scheme.

Key	Function Key Alone	Shift + Function Key
F1	Land Here	To Be Determined (TBD)
F2	Move Forward	TBD
F3	Move Backwards	TBD
F4	Hover	TBD
F5	Move (Slide) Left	Pedal Turn Left
F6	Move (Slide) Right	Pedal Turn Right
F7	Move Up	Wave Off
F8	Move Down	Land
F9	Hook Up Load	TBD
F10	Release Load	TBD
F11	Clearing Turn	Take Off
F12	Pause Simulation	Bring Up Help Files

This presents one potential scheme for the use of function keys in the Phase I prototype. It is clear from the table that many potential arrangements exist. Early in the development of word processors, several vendors attached functions to a multi-layered combination of the function keys. This was great in broadening the abilities of the average user but tended to create substantial resentment among the occasional users who were unable to remember all of the key combinations. In this design, we grouped the signals by type and subsequent usage to facilitate the user acceptance.

There are newer methods around the limitations imposed by the use of function keys. Visual communication is a much faster means to transferring ideas and information. An improvement on the function key concept would be the use of a touch screen with graphical icons used to represent each signal. This would enable the user to simply point at the appropriate signal to input the signal to the computer simulation. No memorization of key codes would be necessary. The icon display could easily be customized to reflect the type of training session. Touch screens can be sensitive to the user's mechanical pressure in making a selection and may be a little slower than a keyboard type input.

The use of the pointing device already being sampled by the computer to collect the signal would be faster than a touch screen. The advantages of this approach of user familiarity and standard interface are offset by the cost of display screen real estate to show the graphical icons. There are trade-offs with any choice for an input device. We are exploring touch screen

technology while we pursue the other two input methods. It should be noted that there is nothing preventing the combination of any two or all three methods in developing the user interface to enhance the system's flexibility.

Estimated Costs

The cost of multimedia ready computer technology is dropping continuously as newer devices are brought to market. The proposed device prototype is being built using moderate range Pentium (75 to 120 MHz) personal computers running the Windows 3.11 and Windows 95 operating systems. The cost of a comparable machine is approximately $2,000 at today's prices. The costs for additional support and display equipment and programming are yet to be determined. In the event that a more powerful multi-tasking workstation is required to meet the computational requirements, the base hardware costs will increase accordingly.

Summary

The research into motion capture systems during the Phase I effort did not yield any candidates for the final system. Some promising technologies such as the inertial sensors have been all but abandoned by the developers. While the motion capture aspect of the VVAST prototype looks somewhat bleak, several innovative ideas are under development that relate specifically to the LSE training environment. These ideas will come to fruition during the Phase II effort. A study published by the Computer Science Department at the Naval Postgraduate School (Frey, et al., 1996) reached similar conclusions about the current generation of commerical off the shelf (COTS) human motion capture systems. They recommended two technologies as best current and best emerging MOCAP systems. The Polhemus Ultratrak Pro electromagnetic tracking system was described as the best currently available for whole body tracking. The inertial sensors were described as the best emerging system. Unfortunately, that technology appears to have been abandoned by the original developer in favor of other applications. While the innovative motion capture systems described herein are developed and implemented during the Phase II effort, there is a need to compare their performance against a recognized standard. Therefore, we would like to include one four sensor electromagnetic system such as the Polhemus FastTrak to facilitate the prototype development during Phase II. It is recognized that this MOCAP system will not be appropriate for the production version due to various operational and facility related constraints. The laboratory use of the prototype will ensure that the prototype is not delayed while the perfect motion capture system is developed.

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COMPUTATIONAL PROTOTYPE

This portion of the project also includes the identification of what components of the system may have the largest overhead in terms of conventional memory for the PC application. While the initial data acquisition and pattern classification will utilize significant system resources in terms of conventional and upper memory, it is recognized that the full version of the proposed device will need to use custom data acquisition software to enable more system resources to be used by the classification and graphic modules.

The computational portion of this project can be divided into several components. The biomechanical modeling phase is designed to create a three dimensional dynamic model of the LSE. This simulation was discussed in the previous section. The pattern recognition and classification module is designed to determine what movement the input data is supposed to represent. This module must be fairly robust to accept the different magnitude and frequency versions of the standard signals. This presents a significant signal processing challenge.

Once the trainee's arm movements have been classified and interpreted in the pattern recognition module, the results are used as inputs to the graphics module where the virtual helicopter's response is determined. The behavior of the virtual helicopter in the simulation can be made more realistic by incorporating some combination of artificial intelligence to create a nominal situational awareness in the simulation. The graphics display must include appropriate representations of the ship and helicopter platforms to lay the foundation for the virtual environment. The underlying behavior of the virtual world objects must appear to follow the laws of physics to build the illusion of presence. Finally, the user interface to this device must allow both the trainee and the instructor to operate the simulator without undue difficulty or discomfort.

PATTERN RECOGNITION AND CLASSIFICATION

It has become clear that the pattern classification module will need to support several component modules. The individual movement module will have to run simultaneously for both left and right arm movements. These two modules (i.e. left and right) must automatically account for variations in trainee size possibly using the anthropometric tables described previously to scale the motion profiles. Once the pattern is classified, we will develop a way of prioritizing the possible subsequent signals to reduce the amount of work necessary in the combined arm pattern recognition module. After a signal is recognized by the computer, it is possible to reorder the signal classification database in terms of what signal would the LSE typically give after the recognized signal. For example, it can be expected that a Take Off signal will be given after the Clearing Turn signal has been given. This was borne out during the preliminary data collection session at OLF Imperial Beach. The Hover signal, on the other hand, has many different possibilities and some programmed situational awareness necessary to reduce the pattern classification and identification time on the next cycle step.

Situational Awareness

Situational awareness is a difficult concept to translate to a computer due to the myriad of observed and learned details humans use to monitor their environment. The human components in the shipboard helicopter evolution have had many hours training to reach a level of awareness sufficient to work on the flight deck. The realism of the simulations will be substantially enhanced if complete event sequences are programmed into part of the virtual helicopter's behavior.

Sampling Frequency

The temporal nature of the handling signals may allow a reduced sampling rate to obtain the same quality data. It is possible to oversample the data and thus introduce noise to the desired signal. The Nyquist criteria states that the sampling frequency must be at least twice the fastest component of the signal under test. Therefore, the results of the biomechanical simulations and practical tests are being used to determine what the minimum sampling frequency is. The minimum signal duration was the Hover Signal which would last approximately one second. The minimum movement duration was approximately 400 milliseconds from start to finish. We are going to begin with a minimum sampling frequency of 30 Hz to capture the entire movements and the transients at the start and end of the motion. This may be modified depending on downstream processing requirements. This sampling frequency also coincides with the standard video refresh rate so the sampling and update cycles may be synchronized at some point.

Non-stationary signals

The average <u>arm</u> movement lasts approximately 600 milliseconds. The <u>signal</u> duration may be anywhere from under two seconds to upwards of fifteen seconds. This presents a substantial challenge to the analysis. Commonly used analytical techniques such as the Fast Fourier Transform (FFT) are able to decompose a periodic signal into a combination of sine and cosine waves with different magnitudes and frequencies that are multiples of the fundamental frequency. The magnitudes of the various harmonics are visible in the power spectrum of the signal and represent a potential source of uniquely identifying the hand signal patterns.

The power spectrum requires a data set with a number of points N where N is a power of two (i.e. 256, 512, 1024) for the algorithm to proceed in any rapid and accurate fashion. FFT algorithms that function with data sets of length N where N is not a power of two are not well accepted. They operate by subdividing the data set into successively smaller blocks by whatever small prime numbers that N is divisible by. The magnitude of the prime numbers has a deleterious effect on the method's accuracy. Depending on the number of processing cycles to transform the data set, classify the pattern and generate the appropriate response at the system level, this limitation in data set size may severely limit the usefulness of this approach.

While the FFT and power spectrum have been used to successfully study regularly repeating signals, the power spectrum can be another source of error. This is a graphical

depiction of the distribution of energy in a signal sorted by frequency. Recall that acceleration profiles are often obtained by taking the second derivative of the position data. The magnitude of the harmonics present in the data set may be significantly increased by differentiation. This is a problem for motion capture systems that simply capture the trajectory of a sensor in space.

The key problem here is the non-periodic nature of the hand signals on a global scale. There are components of each signal (more so for the cyclical than burst signals) that are periodic on a local scale but the global signal is not periodic. The FFT algorithm is also sensitive to transient behavior in the signal. The transition between signals can be a significant problem for a FFT based analysis which tend to push the transients to the higher harmonics thus distorting the power spectrum. This was one of the concerns with over sampling the movements where the LSE is making small personal flourishes to emphasize a particular signal such as a Hover.

Wavelets represent a technique for non-stationary signal analysis. The matrix based algorithm is used to extract features in the input data set and does not have the power of two limitation on the data set size. The fast pyramid algorithm (FPA) works much faster than the FFT algorithms and discontinuities are readily apparent in wavelet analysis. This technique presents several benefits applicable to the VVAST project. The initial processing consists of a series of linear filters after which the amount of data is halved by throwing out every other point. The combined effects are a blurring of sharp lines that potentially fits in well with the need to downgrade the sharpness of the input data in the PC-Video or RF tracking systems to reduce the effects of noise. The compression of the data also reduces the storage requirements. The original signal can be reconstructed from the compressed data using a backwards fast pyramid algorithm.

The back propagation algorithm is well established and eliminates the need for exact rules and descriptions of signal quality. During the training phase, the proper signals can be taught to the network and classified as "Good." This approach should allow the use of either acceptable version of the directional signals such as Move Left without additional operator movement. The use of a wavelet based feature extractors within an artificial neural network is becoming an active research area. Several wavelet analysis tools are available commercially and in the public domain. The documentation accompanying the public domain tools was mainly outlines from introductory graduate level courses taught by the software package authors. The material was interesting but most algorithms required a particular input data file format to use the program. The choice of motion capture system affects the type and format of data available. Modification of the data acquisition and processing modules will enable this type of processing during the Phase II prototype development.

Processor Time Requirements

After the input data set is processed by this module, an output vector is generated that represents what hand signal the input data vector was supposed to be. The actions of acquiring, storing, reading and processing the input data are all controlled by the computer's central processing unit (CPU). It is therefore necessary to optimize both sampling frequencies and the pattern recognition module processing time so the computer is able to perform the necessary calculations to update the graphics display in a timely manner. The timing diagrams are under

development to meet this requirement. While the CPU does control the data bus in the computer, intelligent plug in data acquisition and graphic accelerator cards have reduced some of the burden and improved performance. The analysis may indicate the need for a higher power workstation as the complexity of the graphics display increases. Wavelet analysis requires far fewer CPU cycles than other transform methods and are consequently much faster. This increase in speed can benefit the graphics module by providing more time and resources for the screen updates.

PLATFORM SELECTION

The Navy is presently engaged in a massive budget-driven asset management program. Therefore, it is necessary to select a shipboard platform that will be around as the production version of the VVAST device reaches its initial operational capability (IOC). We inventoried the various air capable ships listed in the 1995 revision of the Resume in terms of number of ships per class, helicopter landing area(s), support facilities, normal compliment of helicopters, obstructions and flight deck size. In view of the changing size of the Fleet, we visited the Navy Public Affairs World Wide Web site initially to review publications by the Navy News Service.

We were fortunate to locate fact files on both ships and aircraft that identified what ships and classes were being decommissioned or transferred to other components/navies. The results of this search were cross referenced with those from the Resume review to develop a short list of likely platforms. The ideal platform would need to present some challenge to the trainees and instructors alike which eliminated the larger deck ships (CVN/LHA/LPD/LHD) from further consideration. The selected ship platform should allow for port and starboard approaches as one instructor recently pointed out.

Ship Model

The list was reduced by numerical superiority to include the following: Arleigh Burke class destroyers (DDG-51 class); Ticonderoga class cruisers (CG-47 class) and T-AFS class supply ships. It is important to remember the type of ship selected is linked to the selection of a helicopter platform for reasons of device fidelity. The next step was to review the Fiscal Year 1997 Navy Budget Excerpts which was also found on the Web site. The Budget Excerpts indicated that the Burke Class destroyers were the only surface combatant being continuously acquired for the next five years. It appeared that the supply ships were being transferred to the Military Sealift Command or other components. After discussing this issue with Dr. Franz, we've elected to use the Arleigh Burke Class Destroyers as the prototype shipboard platform.

The SH-60 helicopter is the primary platform associated with this class of ships. We had collected a reasonable amount of data on the characteristics and performance of the CH-46 Sea Knight during the site visits. This model has been around for several years and the fact file on the Web site indicated that the CH-46 is being maintained until a suitable replacement is obtained. There is a potential replacement vertical replenishment model produced by Kaman Helicopters in ship board trials now. This potential Sea Knight successor is known as the K-Max and is a single piloted aircraft. Therefore, it appears to be prudent to select the SH-60 as the airborne platform for the initial prototype. This will force the early validation of the wind models since the tail rotor equipped helicopters are more sensitive to the winds than the tandem

rotor models. The data collected on the CH-46 will be incorporated into the Phase II effort as an additional platform.

We requested and received a NATOPS Flight Manual for the SH-60 to add to the available data on dimensions, flight characteristics and shipboard procedures. Videotape of a daytime approach and departure pad training sessions in which a single SH-60 was utilized for source data in the prototype. The videotape from HELSUPPRON THREE provided both quality visual and audio data as there were no other aircraft in the area when the Sea Hawk was flying for the students. The NATOPS manual has helped identify the approach patterns and potential emergency situations that will need to be included in the production version of the VVAST device.

Helicopter Model

The helicopter model should incorporate the signals with the flight performance information and other flight related information such as deck edge location, ground effect and wind. While aerodynamically sophisticated helicopter performance models are available from the various manufacturers, the purpose of this module is not to attempt to duplicate that work. We are developing a simplified aerodynamically based and object oriented helicopter model that would enable the use of parameters from the virtual world to more realistically simulate the nuances of shipboard operations. The passage of the rotor wash over the virtual deck edge, for example, can be used as a flag to activate some of the mechanical subsystems (e.g. audio, pneumatic) to increase the simulation fidelity. The actual display of the virtual helicopter will be limited to simple primitives (linked spheres and disks) representing the helicopter to test the system performance in the Phase I effort. Additional graphic displays will be developed in the Phase II work.

The helicopter simulation can be thought of as a series of equations that are modified at each step by state vector which in turn is modified by a combinations of system, simulation and user inputs. The generic model approach will allow modification of basic aircraft and flight parameters such as rotor diameter, helicopter weight, density altitude and winds to create different helicopter models. In the production version of the VVAST device, the different parameter sets will be linked to different graphics files so that the virtual CH-53 looks like a CH-53. It should be noted that the interactive nature of the simulation places restrictions on the depth of the dynamic model. Furthermore, the choice of virtual environment software may also limit the analytical model complexity as varying levels of object dynamics are built into the development software.

GRAPHICS MODULE DEVELOPMENT

The site visits provided excellent opportunities to collect photographic data on the helicopters from different angles and flight attitudes. The second site visit was even more successful in that we were able to photograph the flight decks of several air capable ships from pierside. This was a fortuitous opportunity afforded by a break in the inclement weather. The pictures were helpful in contrasting the various ship platforms listed in the Shipboard Aviation Facilities Resume. The photographs collected during site visits are critical source material in terms of perspective and depth. A special note of gratitude to LT Marshall of HELSUPPRON

THREE who lent seventy one of her personal slides towards this goal. The Phase I effort is a feasibility study and therefore only one ship and helicopter platform are included in the initial prototype design.

The perspective and scenery shots obtained during the site visits are important in defining the needs of the graphics modules in terms of definition and screen updates. The approximate dimensions of the landing area of the selected platform are an average of the dimensions listed in the Resume for the Burke Class ships. We are presently planning out the virtual world to ensure that critical components such as the deck status beacons are included (and easily updated) in the display. A two dimensional top view drawing of an average Burke class flight deck was created using Generic CADD version 6.0 to accurately represent the deck dimensions. This file is being used as a template to verify the accuracy of the custom graphics being developed.

Seven personal computer based three dimensional graphics packages representing the different levels of capabilities were evaluated in the process of determining the optimum virtual environment software development platform. Cross platform compatibility, interactive nature and the number of input devices supported were included along with the obvious virtual environment generation qualities in the evaluation. While many turned out to be good animation packages, few were capable of generating high quality real time interactive virtual environments.

It was impossible to include all available personal computer based 3D graphics packages in the evaluation. A substantial portion of the market has targeted the computer gaming market using VGA resolution (640 by 480 pixel resolution with 64, 000 colors). Most virtual reality and video displays require a higher resolution for proper display. The continuous evolution of hardware and software will improve this situation within the year as the market forces eliminate the non-competitive products. Several hundred graphics engines representing over fifty different three dimensional graphics application programming interfaces are available. The majority of the PC packages are oriented toward static scene generation such as the high end standard represented by Autodesk's 3D Studio. While computer aided drafting (CAD) accuracy is important to the visual display, the required interactive nature mandates strong input device driver support and real time scene generation. The evaluation can be divided into animation and interactive graphics applications. Each type has a particular use within the VVAST environment with the former presenting the ability to develop "canned" animated help files to emphasize a particular point such as a signaling technique.

Although the virtual reality development software packages we have been evaluating (see below) do not appear to answer all of the requirements of the interactive simulation, there are some benefits for smaller components of the VVAST device. The graphics animation software will be incorporated in the signal tutorial module and help files. The interactive software package will be used to develop the virtual environment.

Software Evaluations

The process of evaluating the various software packages was dependent on what the intended application within the VVAST format was. The user interface, features, file input and output capabilities and the quality of the display generated.

PC Animation

Asymmetrix 3D F/X is a good entry level animation software that offers the user several pre-programmed models and animation paths. Animation files can be generated with this package although it is a lengthy process to create a ten second, 24 frames per second animation file with several objects and a generic background. There are a multitude of objects and paths available to the user although creating complex models such as a human form and choosing the path for the arms was a substantial chore. The lack of significant printed or on-line documentation did not help unravel the details of this task. Therefore, we have elected not to pursue any further work with this application.

Macromedia's Macromodel is a general 3D animation package approximately equivalent to the 3D F/X package from Asymmetrix. Caligari's TrueSpace is a high quality animation package with superb texturing capabilities but appears to be limited in input device support for this application. Version 2.0 was released in the Fall of 1996 and contains more extensive graphical features. The icon based non-standard Windows user interface is somewhat difficult to follow and work with. Criterion's Renderware was one of the first personal computer 3D graphics applications with some impressive capabilities. However, there are more extensive packages currently available with more internal real time input device support. Virtus offers an impressive 3D graphics package that is primarily oriented toward architectural renderings and building fly throughs. The pointing device appears to be the major input device supported.

Visual Reality 2.0 provides an impressive array of objects for virtual world creation. Several panoramic 360 degree background graphics files are included with the package. We have been unable to determine how to create a custom panoramic file based on scanned images of the flight deck environment. The interface is somewhat restrictive using "wells" to place the objects one wishes to include in the virtual world. The strength of the software appears to be in developing sequenced frame animation although the interactive interface seems to be rough. The software package has just been purchased by Micrografx and future support is undetermined at this time. We have been able to generate a suitably rendered ocean environment and sky for use as a background. The tutorials were somewhat choppy but once past the initial learning curve, the productivity is increasing steadily. Visual Reality does allow the importing of DXF format files from CADD packages although they can not be incorporated directly in a model. The rendering utilities are much faster and more powerful than other packages we looked at.

We evaluated the Virtual Reality Modeling Language (VRML) version 1.0, a modeling package developed primarily for the World Wide Web. The applicability of VRML to this project does not appear promising in that the source files are primarily coordinate based and a VRML browser is required to view the image to its fullest extent. Version 2.0 of VRML has been released although the static limitation nature of the previous version has not been substantially upgraded. A World Wide Web browser is still required to enter the VRML world. Even one of VRML's authors refers to the language as incomplete and went on to further describe the lack of consensus about an interactivity standard. Therefore, this technology may not be ready for this type of application for some time. As one might expect, the popularity of Internet related software tools may change this sooner than expected. We will monitor the VRML development throughout the Phase II effort.

Interactive Virtual Environment Software

The creation of an interactive virtual environment requires a software environment that has been optimized for real time operation and includes internal support for a variety of input devices. The animation applications evaluated in the Phase I effort did not contain the necessary support for input devices such as typical motion capture systems. The search initially began with real time simulation packages in the UNIX environment. The requirement of the final system to operate within the personal computer environment mandated that the virtual environment development package be cross platform compatible. This is also necessary to ensure the rapid transfer of this technology to other federal agencies and the civilian market. Two applications met this criteria: Multigen and World Tool Kit.

Multigen has an impressive history of interactive real time simulator development with numerous high profile training devices to their credit. This vendor has established a file format that has become the de facto standard within three dimensional real time simulations. The icon based interface allows extensive modeling and world development. Third party models and audio data files may be incorporated into the simulations through the icon based utilities. Multigen runs primarily in the Silicon Graphics environment although some recent articles in the game software development magazines allude to the use of Multigen to develop games for the PC environment. Literature provided by the vendor also alluded to it but this was not clearly stated during conversations with their representative.

Sense8's World Tool Kit (WTK) Release 6.0 does offer a guaranteed cross platform compatibility with versions available for the UNIX, Windows NT and Windows 95 operating systems. The application offers a three dimensional real time simulation environment with input device and 3D audio capabilities. Applications developed in one environment are portable to the other operating systems although there are some minor limitations in the current release for the Windows 95 version (i.e. World Tool Kit Direct (WTKD)). The amount of texturing is currently limited to 256 colors and blending and fog are not yet supported. The limitations in WTKD originate from the use of Microsoft's Direct3D standard in the Windows 95 operating system. The other versions are oriented toward the OpenGL graphical standard found on a variety of platforms. The two standards are competing to become the three dimensional graphics standard. This competition is discussed later in this report. While the dust is settling, it is believed that applications developed for one standard will run on computers using the other standard although at some potentially high performance cost.

Three Dimensional Models

It is necessary to create the three dimensional computer models do that as the spatial relationship between objects changes, the visual display is appropriately updated. There are several ways of creating the models including digitization of an actual or scale model or separate development from multiple photographic images. The number of levels of detail are important along with the spatial relationships between the various components of the model. It is not necessary to draw each polygon if the model is a virtual ten miles away. As the model gets closer to the viewer, the amount of detail must increase to maintain the realism of the virtual environment.

Viewpoint Datalabs offers a number of real time three dimensional models of military ships and aircraft among an extensive catalog. We had the opportunity to review the models as shown on the two demonstration CD-ROMs. While some of the models were very impressive, there were some obvious flaws in the helicopter models. Nine models of the SH-60 were offered on the CD-ROMS. The models did not accurately reflect the Navy model of the Sikorsky helicopter in terms of landing gear placement, cockpit window location and perspective and surface texturing. While the models looked good from a distance, the close in view that the LSE has would rapidly display these errors. A conversation with a Viewpoint representative yielded information on how the different models were developed. Apparently, the newer models simply had a different surface texture applied.

This is not an inexpensive process with each model costing over one thousand dollars to use. Redistribution rights for the Viewpoint models were in the $15,000 range. There are a number of small shops offering three dimensional model development capabilities in the rapidly growing computer graphics field. It is unclear if the products of these contract shops are actually compatible with World Tool Kit even if the appropriate real time file formats are specified. This question can be answered in time as the user knowledge base grows. We are confident that the appropriate models do exist and only minor modifications would be required to ensure that the visual display presented to the LSE trainee are accurate.

Virtual environment software selection

After reviewing the virtual environment packages for the VVAST application, Sense8 Corporation's World Tool Kit was selected as the development software platform. This choice was based on several factors including stability, cross platform compatibility, input device driver support and quality of interactive graphics. This was a difficult choice that came down to the cross platform compatibility of the respective packages. This may not be a significant problem as Multigen and Sense8 are development partners in the simulation industry.

Signal tutorial module

Most software applications contain some sort of a help file that may be accessed by the user to learn or review pertinent information. While the textual information help files were being developed for the VVAST device, it became clear that there is a requirement for some type of animated help files to help demonstrate the signals. Although the instructor can pause the simulation and personally demonstrate the proper signals, this could detract from the sense of presence in the computer simulation. In order to keep the flow of the training session, we have planned and are creating animated help files that demonstrate the proper signal styles. Proper style is considered as a combination of the NATOPS description and the acceptable styles demonstrated by the instructors during the site visits.

The generation and use of audio-video interleaved (AVI) format files through Visual Reality will allow the files to be played using the standard Windows media player. The modular approach of creating separate files for each signal will enable rapid and simple updates when changes occur. The files will be available as a pull down menu selection and are between five and ten seconds long. A comparison of the animated help files with digital video file data will

require fleet LSE instructor feedback for a complete evaluation on the relative effectiveness of each format. We will be looking at the differences between the two display formats to see which gets the message across with fewer distractions. The instructor will be able to run a brief video file from the menu then return to the simulation without leaving his chair. This will reduce the interruptions and maintain the flow of the training process instead of having the student shift focus from the visual display to the instructor and back to the visual display as required.

User Interface

A custom user interface is being created using Borland Corporation's Delphi rapid application development (RAD) tools for the quick prototype development. This approach enables the use of standard Windows interfaces with the interactive C++ graphics and relational database modules. The preliminary design has several open windows that the instructor may use to control the simulation in progress. Delphi enables the developer to make standard calls to the various Windows applications such as the media player or modem and directly to C++ files. The interaction of World Tool Kit and Delphi at the software driver level is yet unknown as Sense8 has announced that it is only supporting Microsoft's Visual C++ for application development. This does not present a significant technical challenge to the VVAST device development as both the Borland and Microsoft C++ compilers adhere to the standard.

Summary

The tools are available to create a comprehensive complement to the current methods of training an LSE using recently available computational tools and applications. Pattern recognition algorithms have matured and become reliable within the personal computer environment. The ship and helicopter platforms to be used within the VVAST prototype development have been identified to further support the fleet implementation. Nine leading animation and virtual environment software applications have been evaluated and selections have been made based on the needs of different modules of the VVAST device. The use of accurate three dimensional models in the simulation is possible using off the shelf computer models with only minor modifications.

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SENSORY FEEDBACK

The technical challenge of creating a sense of immersion in the synthetic environment is as significant as the development of the underlying simulator. The integrative nature of the human sensory apparatus must be addressed in planning how the virtual world will attract and hold the user's attention. Visual, auditory, tactile and cognitive mechanisms must be addressed simultaneously to create the illusive sense of presence. One of the physiologically based challenges is that humans modulate the relative level of influence of each sensory mechanism on a moment to moment basis. This modulation occurs subconsciously for the most part although conscious influences can certainly affect which senses are providing strong input. The creation of a virtual environment for specific task training involves an analysis of which mechanisms may be dominant at what point in the simulation.

The site visits clearly identified that the VVAST device must include some method of training the LSE to walk to one side or another to improve visual contact with the pilot. The field training sessions demonstrated that the LSE trainees will tend to stay in the same location they started signaling in. Several students had to be physically (albeit gently) moved ten to fifteen steps to a different location for visibility considerations. It is recognized that the number of steps was larger than what was quoted by the instructors for the typical shipboard operation. This was most likely due to the training nature of the evolution. Some videotape segment show trainees to lowering one or both arms 30 to 45 degrees from the horizontal plane of the shoulder while repositioning themselves to improve pilot visibility.

VISUAL INFORMATION

The visual sense provides information on the composition and dynamics of the objects present in the visual field. Vision also plays an important role in postural control that may automatically compensate for deficits in other related balance sensing systems (e.g., the vestibular system). While the normal visual field of view may be nearly 180 degrees, we tend to focus on movements and objects in a much smaller cone. Peripheral vision is important in postural control. Severely reducing the amount of peripheral vision available has been shown to induce postural disturbances. Wearable virtual environment displays may be divided into several categories including head mounted displays, shutter glasses and stereo glasses. The use of passive stereo glasses requires that the image display be projected on another screen and modified through the glasses worn by the user.

Each technology is developing rapidly and there are several manufacturers constantly producing new and improved models. The optimal display technology selection involves an analysis of the type of environment to be simulated and what the users are expected to do while using the display device. If the users are expected to sit in a chair during the entire virtual experience then head mounted displays that cover the visual field completely are appropriate. If the users will be walking around, then a less restrictive display technology is a better choice. As most of the technology is still developing, an assessment of the display device's mechanical integrity is important in the final selection. The intended use in a high traffic area with rougher handling than that of a laboratory environment makes the ruggedness of the mechanical design critical to the display device's success.

Potential technologies include augmented reality and projection television displays. Augmented reality devices display the virtual image superimposed on the physical world through a visor or goggle assembly. Reducing the ambient light level in the room by turning off the main overhead fluorescent lights and illuminating one or two small lamps in the mock Primary Flight Control station would serve two purposes: (1) potentially provide enough illumination for safe movement and (2) enhance the augmented reality display by reducing the physical world distractions. It is possible that the level of background illumination would provide sufficient visual information that would enable the trainee to keep his or her balance without consciously trying. The only visual images in the center of the field of view should be from the display device. If the trainee were to turn back and look toward the rear of the room where the mock Pri-Fly is, the one or two illumination sources would provide enough definition that safe movement should be possible without removing the display device. The simulated Helicopter Control Officer work stations in each space provide an excellent location to queue the trainees and place the supervising instructor's workstation.

In the evaluation, we separated video display source media from delivery technology by considering the format of the display and what is required to present the image to the user. This is important in attempting to categorize the myriad of interrelated technologies. NTSC (National Television Standards Code) video from a television set can be displayed on a SVGA/VGA format computer monitor with an inexpensive converter. The reverse is also true. The market is extremely active in this area as many manufacturers implement the available technologies. Currently, over one hundred NTSC to SVGA/VGA converters are available.

Visual Image Source Media

Visual images presented to the users of the proposed VVAST system may originate from a variety of media including videotape, laser video discs, CD-ROM, computer multimedia, digital video disk (DVD) and computer graphics. There are advantages and disadvantages to each type of video source regardless of the eventual display format. Evaluative criteria include the display quality, audio quality and synchronization, duplication, ruggedness, potential content and interactive capabilities.

Videotape Videotape recordings are widely available and cover nearly any subject. The proliferation of consumer videotape products has driven substantial improvements in this technology in the past ten years. Several formats are in common usage including VHS, VHS-C, and 8 mm. Professional broadcast videotape uses a larger tape in a separate format for better resolution. The VHS and compact VHS formats were limited in terms of recording length and resolution. The 8 mm format was developed to address the consumer desire for smaller and lighter video cameras with higher resolution.

This medium provides an easy and inexpensive way to capture and display educational training materials. The content of videotaped information is limitless. While the audio tape is synchronized with the video during the initial recording, it is possible for the audio and video signals to become unsynchronized depending on the quality of the playback device. Duplication of a videotape is technically trivial but there are costs in terms of data quality each time (generation) a tape is copied. A fifth generation tape may be of substantially poorer quality than

the original. Although most professional videotapes are recorded in stereo, the audio signal coming out of the video cassette recorder is typically monophonic. Additional processing is required to produce stereo or three dimensional sound effects. Continued use of a videotape can lead to signal degradation and eventual breakage.

While an excellent means of capturing the initial data, the implementation of a videotaped based display medium for the synthetic environment visual images is not advised in view of the lower resolution and the degradation over time and use. The passive nature of this medium does not lend itself well to an interactive synthetic environment. There are better technologies available.

Laser video disk The amount of video and audio information that can be recorded on a laser video disk is substantially more than on a standard videotape. The data is stored in much the same manner as an audio compact disk, that is pits etched into the surface are read optically and processed to produce the higher resolution video and audio signal. Since there is no contact between the data collection device and the laser disk, there is no comparable degradation over time and use. The encoded sound tracks can contain much more information and are not sensitive to variations in the playback device quality. It is common to find stereo sound encoded on a professionally made laser disk and in most consumer playback units.

The quality of the display from this media is better than that of videotape. There are infinite possibilities for content in this media but it must be planned out prior to the creation of the laser disk. There is no real on site editing or duplication capability in this technology once the disk has been cut. The video must be recorded in exactly the format that will be shown during the simulation. Although the disk is read optically during playback, the large diameter (nearly eleven inch diameter) can make the handling somewhat awkward. The etched surface is sensitive to mechanical abrasion.

The market for this technology has been small but steady for several years. CD-ROM, computer multimedia and the emerging digital video disk (DVD) markets are becoming more and more popular. Although the laser disk has enjoyed a steady market presence for some time, the newer technologies may change that slightly. The potential for use of a laser video disk in the proposed VVAST is higher in view of the increased video resolution and program fidelity. It is relatively simple to remotely control a laser disk player from a simulation control program. Since the laser disk video does not pass through the computer, internal specialized and expensive video processing equipment is not required. While the display quality is superior to videotape, the permanent nature of the laser disk production process makes it necessary to create an entirely new master disk to incorporate any requested or required changes. This could be more expensive in the long run than computer based media. This medium also has the same type of linear nature that affects videotape.

CD-ROM and Multimedia Computers The world of CD-ROM and multimedia computers has literally exploded in the past few years driving substantial and ongoing improvements in the hardware and software necessary to display high quality audio-visual images on a computer monitor. The format for computer video is different from that used to display television and video tape / disk information. Most computers use either the VGA (640 x 480 pixels) or SVGA (800 x 600 pixels) resolution with several different color palettes. The resolution provides an

easy way to calculate the amount of video memory required for the internal video adapter. In order to reduce the software compatibility problems inherent in a rapidly growing market, several standards for digital video and audio compression have emerged from the Motion Picture Expert Group (MPEG).

The first standard, MPEG-1, promulgated methods of displaying full motion video in a window 352 x 240 pixels at 30 frames per second. While this standard was approximately one fourth of the resolution required by the CCIR 601 standard for broadcast video (720 x 480 pixels), it was a good start toward the full screen, full motion video display required to match CCIR 601 resolution. MPEG-2 was the next standard that significantly improved the compression and decompression of video and audio signals for display on a computer at 704 x 480 pixels at 60 Hz screen refresh rate. It is difficult to recreate the original video signal during MPEG decompression as some of the original data is lost during the compression step and is unrecoverable. This may not be a significant problem as MPEG-2 has been adopted for the newly approved HDTV standard. A newer compression/decompression standard, MPEG-4 (MPEG-3 is relevant to HDTV and its status is unknown presently) is under development and should be up for approval in late 1998. MPEG-4's capabilities are still being defined although it appears that this will be an umbrella standard with many separate components.

The relevance of the preceding discussion on compression/decompression standards is to briefly illustrate the technical challenges of displaying full motion video on a computer. The necessary hardware and software are improving continuously. Full motion, full screen video only recently became available in the personal computer market. The quality of the multimedia display is extremely sensitive to several hardware and software factors in the host computer. These include the processing power of the central processing unit (CPU), CD-ROM drive speed and data transfer rate, available random access memory (RAM), video card type and amount of video memory, compression/decompression driver versions and the hard disk type and access time. If the CPU is required to process the entire audio/visual data stream, other computer resources will be ignored while the processing takes place. There are plug in cards that will accept a majority of the processing requirements using specially designed integrated circuits. Some of the more recent video capture cards incorporate bus mastering where the on-card processor temporarily assumes control of the main computer bus to transfer data directly to the hard drive without CPU involvement. This will be discussed in greater detail momentarily. If the computer and any plug in processors become overwhelmed with the video data processing requirements, the playback will begin to appear jerky as frames are dropped. This may be first noticed as incomplete audio outputs. The digitized and compressed video data files are very large and can easily occupy several megabytes of hard disk space for a video clip a few seconds long. The type of hard disk can also affect the playback quality due some internal housekeeping chores. The hard disk controller periodically runs an internal thermal calibration routine to ensure that the drive performance is satisfactory. When this occurs during a video clip playback, the result is a series of dropped frames that in turn produce a jerky movement in the action. A/V hard drives contain a modified controller that suspends the thermal recalibration routine if a data transfer is in progress. These drives are a very recent arrival on the market.

A sub-category of CD-ROM and multimedia computers involves the process for transferring real world video to the computer where it can be edited using a non-linear editing

software tool to create the desired product. Video capture cards are a relatively recent development in the market that were discussed in a previous report. We have acquired two different cards to facilitate the transfer of data from the site visit videotapes to the computer. The digitized video is then to be edited to create files to be used by the prototype. This experience has been colorful to say the least. It has been well established that the typical multimedia kits consisting of a 16 bit sound card and a CD-ROM drive are costly in terms of the number of internal computer resources used. The average cost involves at least two interrupt channels, two direct memory access channels and one base memory address for input/output. If any other cards such as a video accelerator, pointing device or a modem are present, additional resources are used. The introduction of a resource hungry video capture card can cause the system to quickly run out of available resources.

The result of this is that some trade-offs must occur if the system is to be made operational. After working around this challenge, it was discovered that bus mastering capability of the video capture card can substantially affect the system operation by shutting off certain "unnecessary resources." In one case, the pointing device was turned off by the video capture card during data acquisition. Further discussions revealed that the different generations of video capture cards may be designed for different processor speeds. Installing the card into a system with a CPU speed other than what was intended may generate some of these same conflicts during data acquisition.

We tested the FAST AV Master and Truevision Bravado 1000 video capture cards to identify the optimum configuration for the video transfer. The former card is the higher end device and is capable of real time video display. It also appears to be more successful with the higher speed (133 MHZ and above) Pentium processors. The Bravado 1000 unit is reported to be more successful with the moderate speed Pentium based computers. Although both cards operate best in the Windows 95 environment, only the latter card will function in the Windows 3.x operating system. The Bravado 1000 only records the video images to the hard drive. The 16 bit ISA bus sound card is used to record the audio data. Internal software drivers with the video card attempt to keep the video and audio data synchronized. This is not a problem in generic helicopter sound but can become a problem with dialogue and other short duration burst sounds whose synchronization with the visual display are important to drawing the viewer into the scene.

Digital Video Disk (DVD) DVD represents the next large leap in audio/visual storage and compression/ decompression for the entertainment and multimedia markets. DVDs are the same physical size as the current CD-ROM disks but can carry many times more information due to differences in data encoding and storage formats. The standard is was approved by the consortium of manufacturers in December, 1996, after several copyright related issues were resolved. The lossless duplication capable with DVD technology has resulted in a major copy protection issue for the manufacturing consortium involved in the DVD market. Audio information is encoded with the Dolby AC-3 standard for three dimensional effects. The AC-3 technology is discussed further in the next section. If the technology lives up to its potential, there could be a tremendous improvement in the quality of audio/visual material available. A recent market survey reported that the majority of the multimedia software developers are waiting to develop DVD applications until after the release of this technology. The evaluation of

DVD as a medium for visual and audio data storage and retrieval is deferred until the market response to the release is determined and evaluation units are available.

Advanced Computer Video Displays

The computational overhead associated with the continuous display of video data while performing the other required processing tasks can be partially off loaded to a specialized video card. This presents a strategic planning quandary to the VVAST development process. Although personal computers are experiencing substantial growth in the computer animation market, the development of powerful three dimensional graphics and video accelerator cards for the PC is still evolving. Three competing application programming interface (API) standards (OpenGL, QuickDraw3D and Microsoft's Direct3D) are driving the card manufacturers to choose one or two standards to support. Until one standard is generally accepted, the possibility of choosing one card that is not supported by anyone three years from now is strong. The marketing power of Microsoft appears to be pushing the Direct3D standard to the front of a race that is far from over.

We have looked at the video processing capabilities in the UNIX workstation environment. The true multi-tasking environment of UNIX may solve some of the critical timing issues facing the computational modules. X-Windows is a graphical user interface system that has become an industry standard for workstation class machines. The Barco Chromatics IVS 4000 series video cards enable the merging of real time video from multiple sources with no significant degradation in display quality. The CX series video frame grabbers enable the simultaneous display of two live video windows. This is more than can be expected now or in the near future in the personal computer arena.

The combination of the X-Windows interface which is readily controlled by C language routines and double graphics buffers present a very attractive option for use in the production version of the VVAST device. X-Windows will allow processes to run simultaneously in different display windows and data can be transmitted from one window to another. Double buffers are invaluable in providing a flicker free update at a range of resolutions and window sizes. The video attributes may be controlled through a graphical interface in real time.

Although the interface is an industry standard, the IVS 4000 series cards are not supported by all major workstation vendors. The IVS 4000 products will work in the Hewlett-Packard, Sun SPARC and Digital Equipment Corporation Alpha workstations running the HP-UX, Solaris and OSF/1 operating systems. Only the IVS 4100 model will work with the Silicon Graphics work stations. The IVS 4000 series products are designed to integrate radar, sonar and video images in real time for use in air traffic control, command and control and high end simulation applications.

The UNIX environment offers several advantages that were just described but there are some notable costs with moving to this operating system for the VVAST. The interface development is more complex and may not be as easy for the LSE instructor to operate. The use of this operating system will also reduce the portability of the system. Although notebook computer sized UNIX workstations do exist, they are not widespread within the market. An informal survey of local computer repair shops yielded few sites that are conversant in the UNIX

environment. In view of the mobile training team application of the proposed device, there may be more long term expenses in going to a UNIX based system instead of the present development in the Windows 3.x/95 environment. A move to the UNIX environment will effectively eliminate a majority of the civilian market agencies that do not support that operating system. However, given the cross platform capability of the virtual environment development software, the UNIX environment may enable the rapid development of a fully functional VVAST prototype while the PC market matures.

Development Workstation

The choice of a development platform for the VVAST application is complicated by the rapid changes in personal computer hardware capabilities. It would be very easy to choose a new personal computer whose capabilities become somewhat obsolete while the VVAST software is developed. Another concern in the development platform choice is that the knowledge base on the recently released operating systems upgrades may not be as extensive at this time as it will be within six months. Microsoft has recently released an upgrade to its Windows 95 operating system to the Original Equipment Manufacturers (OEMs) that reportedly contains fixes to some memory issues in the initial Windows 95 release. Intel just released (January, 1997) the upgraded Pentium Pro chip with the fifty seven new instructions (i.e. the multimedia extensions (MMX)) for improving the performance of multimedia audio and video files. It is unclear what effect the MMX instructions will have on the interaction of the computer and older ISA bus sound cards at this time. The introduction of Digital Video Disks into the personal computer market will also improve the multimedia performance although the first generation hardware may be quite expensive and less capable than hardware released later in 1997 when the Phase II effort would be startingThe current capabilities of the personal computers are quickly approaching the capabilities of the traditional high end workstation but there are still a few hurdles to be overcome. It is fully expected that the issues listed here will be quickly resolved as the level of experience grows with the combination of new releases and upgrades. In order to facilitate the rapid and cost effective development of the VVAST software application, we have selected an alternative platform to create and optimize the software before porting it to the final production environment. Silicon Graphics (SGI) is a leader in the simulation industry with several stable high end workstation models on the market. The video, graphical and audio technology has been stable for some time. SGI just released a superb workstation known as the O2 with sufficient power to enable a rapid application development cycle at a market price lower than comparable high end personal computers.

The O2 workstation provides substantial video and audio processing capabilities within a stable environment at under $10,000 list price. Independent rendering, video imaging and compression engines have constant access to data and allow real time manipulation of video data. Real time JPEG and MPEG-1 hardware decoding is supported as well as Cinepak, Quicktime and AVI video file compression/decompression (codec) algorithms. The O2's display engine supports up to 1280 x 1024 pixel displays as well as screen capturing and video format conversion in real time without the associated CPU overhead. We have identified several emerging PC video cards that may be able to duplicate these capabilities in the near future. The virtual environment software selected for the VVAST development, Sense8's World Tool Kit, was chosen specifically for its guaranteed cross platform nature. The use of the SGI O2

workstation as a development platform is to facilitate the efficient development of the application in a stable environment while the personal computer hardware and software is allowed to mature. The final version of the VVAST device will be on a Windows based personal computer.

In view of the tremendous amount of data associated with a generic audio/visual data file (over 1.0 MB per second), most multimedia developers have taken to writing custom computer graphics that are less intensive in terms of memory usage but give them more control over exactly what is displayed. The creation of a complex virtual world visual image involves thousands and, in most cases, millions of small polygons. The position of each polygon and any associated parameters such as reflected light or surface texturing must be recalculated for each screen update. While this is computationally intensive, the use of video accelerator cards can improve the system performance.

IMAGE DELIVERY TECHNOLOGIES

Head-mounted Displays

We contacted several vendors who are marketing head mounted display units using television (NTSC or PAL) or computer (VGA) video formats. A consistent trend in the market was that although the manufacturer may be advertising color VGA HMDs as a current product, telephone conversations with the companies revealed that not only were the color units still under development and would not be ready until the fourth quarter of this year but the monochrome VGA units were still being developed. We were advised by two separate vendors not to even consider their earlier products and that the current products were undergoing "significant redesign." In view of the amount of walking and signaling that the typical LSE does during the launch and recovery system, the use of head mounted or helmet mounted displays HMDs may not be appropriate for safety and technological reasons. The use of head mounted displays that completely block our the peripheral vision of the real world is not justified in view of the walking requirements. There needs to be a way of enabling the student to retain sufficient peripheral vision for postural control.

Shutter Glasses

This type of display device operates on the principal of rapidly switch power to transparent liquid crystal display windows in eyeglass frames to produce a shuttering effect. When synchronized to the video refresh rate, a three dimensional image can be created. The cost on this type of display includes the glasses and some type of synchronization software. Chinon America recently introduced a lightweight, low cost ($219) set of shutter glasses under the name of "CyberShades." The glasses are attached to the computer through the parallel port and powered by an external 12 volt power supply. The seven foot cable does not allow sufficient room for the LSE trainee to walk around. The product includes several software drivers and appears to be aimed at the gaming market.

Stereo Glasses

Stereo glasses may have different primary color lenses over each eye to produce a slightly different view of an image much like the old three dimensional cinema films. The separate images are integrated in the brain so the user receives a stereoscopic input. Use of this type of

display device requires that the monitor image be chromatically modified to induce the stereoscopic perspective. This technology is currently used with three dimensional molecular modeling software to help chemists visualize a molecule's structure. The dual color glasses do not appear to have developed the market following that the shutter glasses have.

Projection Television (PTV)

A projection TV system can receive images from the front or back of the screen. The foot print of such a device is dependent upon which methodology is chosen. In view of the limited space available at the proposed installation sites, it is necessary to be creative in the installation process to produce a fully operational system with little or no impingement on the users. In order to provide the trainee with a sufficient platform area to move around in, the use of projection television sets has been identified as an appropriate means of creating the visual display. The desired screen size can be the determining factor in which type of projection television unit is selected. Both types are compatible with most home theater receivers and speakers. The viewing ratio is the ratio of the viewing distance to the height of the screen display. This is an important parameter in evaluating one type of projection TV over another. Conventional analog televisions with an aspect ratio of 4:3 (NTSC display - HDTV has a 16:9 display aspect ratio) provide sufficient definition for viewing ratios up to about 4. This effectively limits the display size to 28 inches vertically or 35 inches diagonally. Although larger sets may be purchased, the scanning lines become visible at lower viewing ratios. Interlace flicker, fuzziness and color edge effects also become visible to any viewer. It is necessary to increase the horizontal resolution to eliminate the fuzziness. This can be a real distraction for the viewer in a training simulation if this parameter is ignored. Flicker becomes a problem if the frame repetition rate becomes too low. The movie theater approach where the display is bright and the area surrounding the display is dark is optimal in terms of illuminating the retina and avoiding flicker effects.

Rear Projection Television Rear projection television sets are considered part of the mid range home theater market and have screen (diagonal) sizes ranging from 35 to 60 inches. The display is best in a subdued light as reflected ambient light can obscure the darker images on the screen thus making edge detection difficult. One part of the image in the proposed device that may be compromised by the reflected light is the flight deck and surrounding ocean at the bottom of the screen. The foot print of rear projection television is a rectangle approximately 18 to 24 inches deep and four to six feet wide. The height of this type of television is fixed and may only be raised by constructing a platform underneath the unit. The list price range for these models ranges from $700 to nearly $2000 depending on screen size, features and manufacturer.

The use of a rear projection television could potentially create a problem at both fixed installation sites in the form of a small reduction in available training space. The proposed installation site in the HELSUPPRON EIGHT spaces has a small stage where the display unit would most likely be placed. This could present a significant obstacle to the instructor due to the already limited amount of real estate on the stage. The implementation of a front projection screen display unit in the proposed VVAST device would have the minimum impact on the fixed installation sites and answers the question on the best video display method for the mobile training team components. The use of this technology in a semicircular theater type installation

will enable the incorporation of three dimensional sound and directional air vents to enhance the illusion of presence. Recent advances in computer sound and speaker technology have created a three dimensional "feel" to the sound that is more realistic than the older practice of simply mixing channel outputs.

Front Projection Television Front projection televisions operate by projecting a bright light(s) through an active color matrix liquid crystal display. The screen sizes may be much larger and diagonal sizes over 100 inches are not uncommon. The display units are much smaller than the rear projection TVs and may be mounted on small (e.g. two foot by two foot) platforms suspended from the ceiling. Typical front projection units can weigh as little as 14 lbs and display images from multiple video sources including television and computers. This presents a solution to the challenge of supporting the mobile training teams. While not a completely immersive (i.e. goggles) approach, the use of a portable multimedia projector to display the imagery from a notebook computer does offer an easily portable system. This configuration would also be well received within the other markets as multimedia projectors are becoming more and more widespread. Some front projection units include integrated audio units some with either SRS or Spatializer three dimensional acoustic technology built in.

The display screen may simply be a passive reflecting media such as the screens presently installed in each multi-purpose room at the LSE/HCO schools. The brightness of the front projection televisions have been improving rapidly in the last three years. The advent of digital satellite systems and DVD technology should drive the prices down in the next two years. The range of list prices for front projection television systems capable of 100 inch screen sizes went from \$3500 to over \$10,000 depending on features and manufacturer. A one hundred inch diagonal screen size can be created easily with a twelve foot projector to screen distance. This fits in well with the available space within the two multi-purpose rooms.

AUDIO DISPLAYS

The sound of the approaching helicopter is used by the LSE as a secondary means of monitoring the evolution in terms of spatial position and the mechanical status of the aircraft. The nature and level of the sound is important during the most critical segment of the LSE's work. While this level can be duplicated to some degree by increasing the speaker volume, the localization and character of the sound source(s) must be factored in. The use of high volume levels indoors is particularly inappropriate in a mixed office-classroom environment. Therefore, alternate means of delivering the sound not only to the trainee but to the other trainees who may be observing in the back of the room must be developed. One of the initial concepts we had proposed was to modify a standard flight deck cranial to incorporate the speakers and potentially the video display device. While it is not necessary to provide the observers with a high volume of sound, it would be advantageous to the overall training package to direct some sound toward the observers to enhance the experience. It is possible that this feature may be obtained inexpensively using off the shelf components from the home theater audio market.

Each helicopter has a distinctive noise that must be spatially linked to the visual display before the illusion of presence in the virtual environment can be created. The frequency spectrum of the audio signal identifies which frequency bands have the most power and is used to design the audio system to optimize the sound reproduction. The videotape recently provided

by the LSE instructors at HELSUPPRON THREE has several good quality segments of pure SH-60 sound. The CH-46 and SH-60 sounds presented to the LSE during the pad operations are still being analyzed. Indirect transfer of the audio information through the use of a microphone produced unsatisfactory results for any further analysis. Therefore, we have been gathering the audio information directly off of the source video tapes using the video capture boards. This has presented some interesting challenges as described earlier. We are creating a library of sound files for use in different parts of the simulation. Non-standard noises such as compressor stalls can be added on top of these files within the operating system environment to add variety to the simulations.

Additional helicopter noise tracks can be added during the Phase II effort. Spectrum analysis is used to determine the relative magnitude of the various frequency bands needed to accurately reproduce the audio experience. This is important in the implementation of the VVAST device since low frequency sounds can travel through a structure such as a building much farther than the middle and high frequency signals. User satisfaction of any device includes feedback from the actual user and those around it. In this case, it would be of sound reasoning (no pun intended) to ensure that the audio system is precisely designed and that the device does not provide an audible or sub-audible (i.e. a low frequency "thumping" that is felt more than heard and that travels easily through a building) interference to the wing commander whose office is located directly below the multi-purpose room at the North Island site.

Division of the audio output from the VVAST device into stereo channels to both the trainee and observers will require some further research. Recent advances in spatially distributed sound offer the potential to link the visual and audio displays. Some methods of coding three dimensional sound require preprocessing of the sound and specific hardware to create the illusion. There are other methods that do not require this preliminary work. The virtual environment development software package selected for the prototype development does allow a sound source to be linked to a virtual object.

Auditory Physiology

The human hearing system can detect signals from approximately 20 Hz to nearly 20,000 Hz. Sound arriving at the outer ear is reflected by the pinna through the ear canal to the tympanic membrane. The complex shape of the pinna and the outer ear canal substantially affect the spectral shape of the sound that reaches the tympanic membrane. The variations in air pressure are transformed into mechanical vibrations at the membrane before transmission through a series of three tiny bones (i.e. the ossicles) to the cochlea. The impedance of this small mechanical system is well matched to transmit signals from 300 to 3000 Hz. Once the vibrations have passed through the cochlea's oval window, the mechanical vibrations from the middle ear cause the membrane covering the cochlea's oval window to vibrate. This causes the fluid within the cochlea to move thereby exciting tiny hair cells located on the cochlear basilar membrane. The wavelength of the sound affects only a small portion of the hair cells whose vibrations activate the nerve signals that are used by the brain to decode the loudness, direction and meaning of the sound. Above the cochlea, neurons from both cochleas are extensively interconnected at various levels of the auditory system before and within the auditory cortex to provide the higher level functions necessary to interpret the sound.

Sound is described in terms of decibels relative to a base sound pressure level. The interpretation of a sound level changes proportionally with the cube root of the actual sound intensity levels. The human auditory system is capable of discerning nearly a trillion different sound intensity or one million times increase in basilar membrane movement amplitude. This scale compression enables the ear to interpret this as approximately 10,000 different sound levels. The sensitivity of the auditory system is frequency dependent with the response appearing as a trough on a amplitude - log frequency plot. Human hearing is most sensitive to sounds around 3,000 Hz.

Loudness is determined by three mechanisms. The amplitude of vibration of the basilar membrane hair cells increases as the loudness increases. In addition to the hair cells that are vibrating at the exact frequency of the input sound, hair cells on the fringes of the resonant area begin to vibrate as the amplitude of the sound increases. Finally, there are hair cells that do not actively generate nerve action potentials until the vibration of the basilar membrane reaches a certain level. The combination of neuronal activity from these mechanisms provides the data necessary for the brain to determine the loudness of a particular sound. There are reflex mechanisms that may reduce the perceived loudness in order to prevent damage to the cochlea. The reflexive activation of two ossicular muscles can reduce the amplitude of sounds below 1000 Hz by 30 to 40 decibels. This 40 to 80 ms latency reflex protects the cochlea from damage from loud noises and allows the listener to concentrate on sounds above 1 KHZ where information is transmitted in voice communication

There are two mechanisms used by the auditory system to determine the direction of a particular sound. The phase lag mechanism compares the difference in the time of arrival between ears (i.e. interaural) to determine the direction of the source. This is most accurate for sounds below 3,000 Hz. Once the wavelength of the sound (i.e. wavelength = Speed of sound (340 m/s at standard temperature and pressure) / frequency) decreases below the interaural distance, the brain is not able to discriminate between phase differences of one or multiple cycles. Above 3,000 Hz, the head acts to absorb and reflect the shorter wavelength (higher frequency) signals. The brain uses the comparison of the intensity level between the ears to determine the direction of arrival. The phase lag method is considered more accurate than the intensity comparison in most cases.

3D Sound

Sound is perceived directly and indirectly. It is the combined character of the directly radiating and reflected sounds that adds the fullness to the audio tracks. The development of stereo recording techniques many years ago enabled the recording engineer to position a sound from a particular direction between the speakers by adjusting the channel gains. Three dimensional (3D) sound spatialization describes a process in which the incoming signal is modified to reproduce the real world acoustic properties within the virtual environment. This process has been improved on tremendously and several competing technologies are vying for the major share in the 3D audio market. The general technologies involve a combination of multiple speakers, encoded and decoded audio signals or post processing on previously recorded sounds or a mixture of the three methods.

Dolby Laboratories has been a pioneer in the audio engineering field with numerous advances in noise reduction and sound processing through proprietary encoding and decoding techniques. The Dolby equipment is well established within the entertainment, broadcasting and consumer electronic markets and appears to be the standard by which newer technologies are measured. The Sound Retrieval System (SRS) is a product of SRS Laboratories that applies a modified transfer function to the audio tracks to create a more spatially distributed sound presentation to the user. The Head Response Transfer Function (HRTF) is a mathematical description of how sound is affected by the head and ear over a range of frequencies and azimuths. The Spatializer product line was developed by Desper Products, Inc., to use a different psychoacoustic approach to produce the 3D effects.

The post processing approaches may inadvertently overprocess the audio tracks producing a diffuse and indistinct sound. SRS Laboratories requires each of its licensees to provide the listener with a means of turning the sound expansion effects off. The Spatializer devices use a proprietary "Double Detect and Protect" circuit to sample the incoming audio signal for indications that it has already been processed using a sound expansion or decoding algorithm.

While the majority of the work in virtual reality has focused on the visual presentation, it has been shown that the audio component is critical in creating the illusive sense of presence. Hendrix and Barfield (1995) reported on a series of experiments where spatialized sound was used to enhance the sense of presence in a virtual environment. Although the spatialized sound did produce a statistically significant increase in the subjects' reported sense of presence over the non-spatialized sound, the limitations of the experimental apparatus did not account for reverbation (indirect sound) or head movement. The spatialized sound did increase the fidelity of the sound sources and the subjects' sense that the sounds emanated from specific locations.

A surprising result of this study was that the spatialized sound did not appear to affect the realism of the simulation despite a stereoscopic display and other visual features. The use of generic HRTFs in the sound generation process may have led to reduced significance levels. The lack of reverbation in the virtual environment and subject head movement may have also affected the sense of presence. The movement of the head without a corresponding adjustment in the sound presentation may have presented an indistinct image of the audio source and thereby decreasing the sense of presence. It is believed that giving the subject a challenging task to perform within the virtual environment will allocate more cognitive resources to the synthetic world and thus increase the sense of presence. This is precisely what the proposed VVAST device intends to do. The use of 3D audio technology to provide a spatially distributed sound field while the subject attempts to land the virtual helicopter on spot is an ideal proof of this concept.

3D Audio Technologies

Dolby Laboratories

Multichannel sound has been used for many years to create a more immersive experience for the audience. Theaters use a center channel in addition to the left and right channels to

sharpen the acoustic perspective of on screen sounds. Dolby Surround is a two step encode and decode process involving both recording and playback. When sound is recorded, four tracks (left, right, center and surround) are encoded onto two audio tracks using Dolby labs equipment. Dolby labs equipment is required to decode the signals and produce the surround sound experience. Existing systems may be upgradeable depending on the listener's interest and budget.

Both Dolby Surround and Dolby Pro Logic receivers decode the surround channel information from encoded program material and feed it to a pair of surround speakers placed on the side walls adjacent to the listening area. The basic Dolby system feeds the entire program the left and right speakers in a normal stereo mode with no additional processing. The surround speakers are fed a surround signal derived by a passive matrix decoder. The Left and Right speakers then create a phantom center channel for a few listeners seated in the center of the sound field. A fixed Surround channel time delay of 20 ms is used to enhance the environmental presentation of this channel's information.

Dolby Pro Logic receivers derive the separate center channel to keep dialogue and other central sounds firmly localized on the screen. There are four output channels: Left, Center (normal, phantom and optional wide modes), Right and Surround. Pro Logic units utilize an active matrix decoding circuit to supply higher separation among the four channels along with more accurate sound positioning to widen the area where the 3D sound effects are heard. The AC-3 encoding standard is being incorporated in the newer Pro Logic receivers

The left and right channels carry the entire audio bandwidth in both surround and conventional stereo systems. The center channel in a Dolby Pro Logic system carries dialogue, special effects, music and other on-screen sounds thus localizing these sounds to the screen. Center channel speakers can be a little smaller than the Left and Right channels but should be equivalent in terms of mid to high frequency response. Speakers with multiple small drivers may color the sound for off axis listeners.

The Center channel has three modes: Normal, Phantom and Wide. In the Normal mode, the low bass (< 100 Hz) sounds are removed from the center channel and redistributed it to the left and right channels. Low frequency sounds do not affect the directionality cues. This mode lets enables good system performance with a less powerful center speaker (i.e. ½ but not less than 1/3 the power of the left and right channel speakers). The actual power required is a function of speaker sensitivity and whether or not center channel equalization is used. The Phantom mode does not require a center channel speaker. It redistributes all center channel information to the Left and Right channels. Sounds will appear to pull toward the nearer speaker for off axis listeners. The Wide mode is a an option on many current receivers. This mode delivers the entire audio bandwidth to the center channel and should only be used if the center speaker is the same size as the left and right speakers. The center channel must reproduce bass levels equivalent to those in the left and right channels and therefore should have the same power output.

The surround channel does not contain any information below 100 Hz or above 7 kHz. When played back, the surround channel passes through a 7 kHz low pass filter and a modified

Dolby B type noise reduction processor in the decoder to reduce the noise and distracting high frequency signals that might leak through from the front channels. The surround sound is also time delayed slightly to increase the apparent separation between the front and surround channels.

Although some low bass may slip through, there is no need for the surround speakers to reproduce it as only the front channels' low bass needs to be heard. Full treble response is recommended for surround speakers because other processing modes and future delivery formats (i.e. Dolby Surround Digital with the AC-3 encoding standard) may support it. The surround channel is currently monophonic. This channel typically contains low level atmospherics such as the wind through the trees and the occasional special effect to avoid drawing the listener's attention away from the screen. The use of this channel is still somewhat of an art form.

Properly creating the directional effects and diffuse ambiance require an evenly distributed mixture of directly radiating and reflected sound. The former are used along the sides and back of movie theaters to create a wide immersive sound field. Too much direct sound can make the speaker location obvious. Too little directly radiated sound produces a directionless feel that is adversely received. Left and right speakers should be arranged at an angle of 45 degrees to the listening area. If a center speaker is not included in the system, it is necessary to place the speakers a little closer to the screen center to achieve a good integration of the sound. The center speaker when present should be as close to the screen as possible and at the same height as the left and right speakers to achieve the best directional effect. The front of the center speaker should be behind the front of the left and right speakers to prevent an adverse effect on the sound perspectives of off axis listeners.

Surround speakers may be direct or dipole radiating and should be placed alongside the seating area (in a home theater installation) two to three feet above the listeners and aimed directly at each other to create a mixture of direct and reflected sound. If the room is full of sound absorbing materials, the speakers should be aimed toward the rear wall or ceiling to increase reflections. Subwoofers only reproduce non-directional low bass sounds and therefore do not need to be in the line of sight with the viewer or listener. The accuracy and smoothness with which they reproduce low bass does depend on their placement. The optimal subwoofer placement(s) produce a clean full bass sound that does not have a booming or thudding character.

Program sources may be from several sources with the direct digital interface of laserdiscs and satellite broadcasts providing the best sound sources. Although most other audio/video sources (cable or broadcast TV and VCR) may record in stereo, the output audio signal is typically monophonic in format. It is strongly recommended that the audio sources that have a proper two channel output capability be connected to the surround decoding unit to capitalize on the encoded information.

The application of Dolby technology to the proposed VVAST device will require additional effort in terms of the use of specialized recording equipment to properly encode the signals. The benefits of this approach would be in the perceived quality of the sound using AC-3 compliant receivers. The cost of such equipment or the availability of rental equipment of sufficient quality are not yet known. The portability of the proposed device is directly affected

by the requirement for multiple speakers. In addition to the increased number of components, the speaker placement at each remote site where the VVAST device is used can be an issue affecting fleet acceptance. If the 3D sound effects are not detectable by observers located outside the "sweet spot" (where the speaker output is focused), the sense of presence will be much more difficult to create since the majority of users will have their first exposure to the system as an observer. The adjustable Surround channel time delay in the higher end Pro Logic receivers does offer a means to compensate for differences in room size and proportions.

The Dolby AC-3 standard is being implemented in both the High Definition Television (HDTV) and Digital Video Display (DVD) markets. It does promise to significantly improve the sound quality of both consumer home theater and computer multimedia but may not provide all of the features desirable in the proposed device. Fortunately, there are compatible technologies entering the market that compliment the new encoding/decoding algorithms and fulfill many of the audio requirements for the proposed device.

SRS Laboratories

The process of recording sound uses microphones that are generally insensitive to differences in direction. Omni-directional microphones have a flat response for 360 degrees azimuth. Cardioid microphones have a flat responses on the front and sides but a zero response to sounds located in the rear quadrant. The same comments on directional insensitivity can be made for changes in the elevation of the sound source(s). Therefore, the azimuthal and elevation information is buried in the standard two channel stereo recording. SRS Laboratories has developed and patented a method of recreating the three dimensional sound by processing the incoming sound through a matrix to recover the directional characteristics.

The Sound Retrieval System (SRS) technology was originally developed at Hughes Aircraft to enhance the quality of sound from the in-flight entertainment systems in Boeing wide body aircraft. As the market shifted, SRS Labs was created and has licensed the SRS technology to over 70 major computer and consumer audio manufacturers. In the Auditory Physiology section, the important role of the outer ear and ear canal in shaping the sound presented to the auditory system was discussed. Some frequencies are reflected directly to the ear canal by one or more pinna surfaces. Reflections from multiple surfaces may reinforce or cancel the original sound. Other frequencies may be absorbed or reflected away from the ear. The angle of reflection from the outer ear surfaces is dependent on several factors including the azimuth and direction of the sound source.

The SRS system filters the incoming signal to create Sum and Difference channels. The sounds present on both channels with equal amplitudes comprise the Sum channel. Those sounds with uneven amplitudes between the channels are part of the Difference channel. During the signal processing modules, the channels are filtered and modified to restore the directional information.

The last step in the SRS involves the re-mixing of each channel to produce the two stereo channels. In this manner, the azimuthal and elevation cues are incorporated in the modified stereo signals. There is no "sweet spot" outside of which the 3D sound effects are not detectable.

The directional cues are present in the majority of the sound field generated by two speakers. The placement of the speakers is also far less sensitive than those for Surround Sound. A separation of approximately six feet will create a larger 3D sound field using the SRS system. An optional subwoofer channel is available to improve the immersive sensation of the expanded sounds. The proprietary technology prevents amplification of frequencies where the human hearing system is more sensitive to phase differences and therefore reduces directional errors.

While the SRS technology is rapidly expanding several market segments (consumer audio, computer multimedia, car audio, professional sound and video and arcade games), the issue of compatibility with other audio processing systems becomes important. SRS does not require any preprocessing of the sound during the recording process and is fully compatible with the incoming AC-3 encoding/decoding algorithm. The AC-3 Standard uses two channels to store the encoded information. The use of SRS is neither additive or destructive and the output signal is enhanced prior to the decoding and distribution.

The determination of the extent of a 3D effect is often a subjective assessment. We compared several mid range PC stereo speakers attached to nearly identical sound cards for the directional cues. One set of speakers did have the SRS Laboratories' SRS technology integrated with the hardware. The perceived directions of the sound sources from a musical CD tracks were considerably different for the SRS equipped speakers than for the non-SRS equipped models. The consensus of opinion was that the sound character was more full and better directionality with speakers incorporating SRS processing were used.

At the November, 1996, COMDEX show in Las Vegas, SRS Labs and Chromatic Research announced the joint development of the media processing chip that incorporates all multimedia related functions and the SRS technology. The Mpact media processor includes 2D and 3D graphics acceleration, MPEG video, audio, fax/modem, telephony and videophone equipment within a single component. This unit will also be able to play a DVD file and decode the Dolby AC-3 encoded audio tracks. The six channels are then fed to a improved version of the SRS 3D sound known as TruSurround for subsequent real time processing. The modified audio signals are then re-mixed for output through two standard PC stereo speakers.

Prior to this development, dedicated MPEG-2 and Dolby Digital (AC-3) hardware were required in the computer to achieve this goal. Both MPEG-2 and the AC-3 decoding process are computationally intensive and require a significant portion of the CPU's time. Although Intel has added over fifty new instructions to the base set of processing commands for the CPUs to enhance the multimedia capabilities (i.e. the MMX extensions), this has yet to be widely implemented as most developers are still in the learning curve. It is hoped that the additional instructions will enable the simultaneous playback of a DVD title while running Windows. The Mpact media processor with SRS's TruSurround technology is scheduled for release in the Spring of 1997.

The potential inclusion of DVD technology in the proposed VVAST device with the benefits offered by a combination of the SRS audio technology could quickly produce an immersive environment for both the trainee and the observers. The use of only two speakers substantially improves the portability of the proposed VVAST simulator. This technology is

worthy of further review and incorporation into the prototype development.

DPI Spatializer

Desper Products, Incorporated, has developed a proprietary 3D audio "Spatializer" technology based on an analog 20 pin integrated circuit that creates a hemispherical sound field with two speakers. The two stereo channels (i.e. Left and Right) are used to derive two additional channels, the Sum and Difference, through the use of standard adder and subtractor circuitry. The Sum channel contains all of the information present in both channels. This channel provides all sound information that would be perceived as originating at the mid point between the speakers at what may be considered a phantom point. The Difference channel contains the information found on only one channel that gives the subtle clues necessary to extend the perceived sound source angle beyond the speaker boundaries. In this manner, two physical (front) and two virtual or phantom (rear) speakers are used to enhance the listening environment.

In order to prevent the overprocessing of the incoming audio signal, the Spatializer uses a proprietary Double Detect and Protect (DDP) circuitry to prevent the output sound from becoming diffuse and indistinct. This circuit operates by measuring the spatial and frequency content of the incoming signal and does not require user intervention. The main feature of the Spatializer technology is the manipulation of the Difference channel to create the illusion of two phantom rear speakers. "Panning" from the main speakers to the virtual speakers is used to extend the perceived sound location outside of the two physical speakers. The Sum channel is not modified by the processing technology as it is assumed to be properly mixed and equalized during the recording process. The illusion of the virtual front speaker is more effective than that created by the phantom rear speakers. This is a reasonable comment in view of the premise that the Spatializer technology was designed for a two speaker system.

A software based digital application featuring the Spatializer audio signal processing technology was released recently for use by game and multimedia developers. The Spatializer DSP mode offers three modes: Spatial Expansion (off center sound enhancement), Directional Positioning (locate and move various sources within a 270 degree arc) and Spatial Synthesis (convert monophonic data to stereo format). This is a single step process with no decoding necessary. This is the first software release in a long series of hardware products that have been used in the recording, television and movie industry. The majority of the products are intended to provide the recording engineer with the ability to move the sounds around in a 270 degree arc centered on the listener.

The use of this technology within the proposed VVAST device may provide 3D sound effects if the system is limited to two speakers. The actual physical speaker configuration has yet to be determined. While the Spatializer system has been used in the audio engineering of several record, film and television projects, it does not seem to have a strong presence in the market in comparison to the other two technologies perhaps due to its relatively recent arrival. Therefore, further evaluation of the Spatializer technology for this project is not warranted.

Summary

The three dimensional audio market is expanding rapidly and significant advances are occurring almost weekly. The combination of AC-3 encoded material with the SRS 3D sound enhancement appears quite promising in being able to create an immersive audio environment for the trainees and the observers without the limitations inherent in attempting to focus speaker sound fields on a particular listener location.

TACTILE DISPLAYS

Humans have many redundant sensory mechanisms for transducing the mechanical forces in the physical world into neural input that can be interpreted cognitively. Mechanical pressure sensors in the skin and hair follicles can be displaced by wind. Nerve signals are generated by the movement and the impulses are conducted to the brain's sensory cortex for interpretation. Sensory inputs resulting from motion in any direction arise from proprioceptive sensors located in the inner ear, muscles, joints and internal organs. In order to create a sense of presence in a task oriented virtual environment, it is necessary to address the components of the simulated task that involve these mechanisms.

One consistent comment from the LSE instructors was on the necessity of linking the displays to the rotor blast. The physical sensation of the rotor blast is an important visceral sensation that the instructors feel needs to be incorporated into the device. The major physical sensation of the rotor blast is the distributed force on the torso with wind sensations affecting the face, arms and legs. Once the LSE is in a stabilized position (i.e. the boxer's stance), the smaller frontal surface area of the arms and legs does not seem to engender a large distributed force. One noticeable sensation is the flapping of any loose clothing in the rotor down wash. Since the LSE's head is covered with personal protective gear including a cranial, sound protectors and large goggles, wind sensations across the face and head are not that substantial.

We did look at the proposed installation sites for possible ways of including some type of rotor blast simulating component in the VVAST device. These observations are helpful in reducing the airflow system complexity by targeting regions that are more sensitive to the wind sensations. The benefit of this approach to the air handling system in the installation sites include less wind generation in the enclosed space. The use of directional air vents with integral sub-woofers has been suggested as a means of enhancing the tactile sensations of the simulator. In order to maintain the flow of the simulation, the VVAST air handling system must be capable of rapidly producing a diffuse yet sensible air flow and just as quickly shut off.

As the virtual helicopter approaches the landing area, it is possible to use a custom air handling system to produce and direct the flow toward the trainee who would be able to sense the virtual rotor blast with the mechanoreceptors in the skin. This technique should provide a more visceral sensation of presence in the simulation. Clearly, the room air handling system will have to account for the movement of air in the simulator. The air handlers can be controlled from the computer using established, off the shelf technology. This will be addressed as the prototype takes form. The integration of low frequency speakers into the proposed air handling system is intended to capitalize on an existing resonance chamber to further amplify the low frequency audio signals and enhance the visceral sensations.

There might be a low cost solution to this part of the design challenge from the facility energy management field. Air doors are a recent development that have found wide acceptance in high traffic public facilities. When the door is opened, a relay is opened and the fan motor quickly generates an air curtain to keep the environmentally controlled air inside and the (hot or cold) ambient air outside. The added benefit of the air door creating a loud, broad spectrum white noise signature may allow a reduction in the simulator's audio power requirements and increase the sense of presence. The white noise may eliminate the need for substantial low frequency speaker output.

Motion related sensations

The virtual world objects must also behave like the real objects they are modeled after. The physical system is very dynamic with both the ship and helicopter subject to powerful physical forces. The ship's flight deck is subject to both random and regular pitch, roll, yaw and heave excursions during normal operations. The instructors we interviewed were asked to prioritize which type(s) of deck movement were most common in their LSE experiences. The responses ranked the rolling sensation as the most important deck movement sensation. Pitch movement was the second most common response. Roll and pitch limits are specified for each helicopter model in NWP-42 and the NATOPS Flight Manuals. Yaw was not mentioned as a significant feature. Heave was described as a transient vertical elevation change.

Dr. Franz had mentioned a project at the Naval Air Warfare Center, Training Systems Division, Orlando, that involved a full motion platform in a training device for training machine gunners in a simulated moving vehicle. We were referred to the lead engineer, Mr. Ed Purvis, by Dr. Jeff Horey of NAWCTSD Orlando. The platform in question is a two degree of freedom, electrically powered device controlled by the desktop personal computer (a 66 MHz 486 DX-2 CPU) that is also running the entire simulation. A laser disc video player is used to provide the graphics display. Motion profiles were recorded using accelerometers mounted on the moving vehicles and are played back. This is the same approach that we would like to use to collect motion data for a similar type platform to be incorporated into the production version of the VVAST device. Further development of the motion platform capability of the simulator will occur in the Phase II effort when we have a better understanding of where the VVAST device will be installed since facility requirements will be critical at that point.

COGNITIVE ISSUES

The sense of presence in a virtual environment requires some willingness to participate on the user's part. The training situation that the LSE trainees will use the device in will go a long way toward developing the user "buy in." The combination of the various sensory feedback methods will further that goal. In addition to these features, the inclusion of proper flight deck protective and signaling equipment (cranials, goggles and flashlight wands) will bring more minor yet tangible physical sensations to the user. This should substantially advance the fidelity of the simulation. The cognitive issues include how the VVAST device reproduces the flight deck experience and do all the players (ship, helicopter, etc.) behave as the expert user recalls. The latter criteria is dependent on the underlying programming and structure of the graphics display.

Two other cognitive issues are worth examining. The simulation must provide a means for the trainee to understand the sense of purpose (i.e. "Why am I using this device?") in using this method of training. Without instructor support, any training system can become an entertainment device. This is why the interface design is critical to the success of the project. If the instructor's interface with the device is difficult or unfriendly, the frustration will quickly become apparent to the students and the potential buy in will be that much harder. The training device must also present a challenge to the student and remain unpredictable. The mastery of various video games by repetition causes the game to lose its appeal and acceptance rapidly. The simulation must show the trainee the consequences of improper actions (i.e. a Move Forward signal with the helicopter well forward of the T line). If the user realizes that the scenario is not "canned" and that some skill is necessary to be successful in the simulation, they should take it more seriously than a simulation where the user is "invulnerable with unlimited weapons."

The presentation of multiple branched scenarios that can be selected by the instructor can keep the training from becoming stale. This concept is currently under development and more information will be included in the next report.

Sensory Integration

It is possible to include the visual, audible, tactile and motion features into the graphics display but potential exists for creating conflicting and discomforting physiological sensations in the users. While the trainee's internal motion sensors (i.e. the vestibular apparatus, muscle spindles and the graviceptors in the trunk) report to the brain that the body is stable, the pitching, rolling and heaving visual display is presenting a different picture of the environment. There is a substantial body of research that demonstrates that the visual system has the most powerful drive to the postural control centers in the brain. The resulting sensory conflict can produce motion sickness like symptoms in many individuals. This is not uncommon in flight simulators where the visual display indicates aggressive movements in several dimensions yet the full motion simulation systems are inactive. The discomfort can develop even in experienced pilots. An ideal way to reduce the potential for sensory conflict generated motion related discomfort is to synchronize the movement of the platform the student stands on with the graphics display. The visual, vestibular and graviceptor sensory inputs would be more closely aligned in this case leading to a reduction of the physiological discomfort.

Summary

The creation of a compelling virtual environment results from a combination of several factors. The rapid developments in the computer multimedia field have produced a situation where commercial off the shelf components can be used to create a near immersive training environment.

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TECHNICAL ISSUE IDENTIFICATION

The purpose of this objective was to identify the hardware, software and facility related issues that must be addressed in the implementation of the VVAST device to support the LSE training mission. We identified several hardware and software resources during the two scheduled site visits. Desired hardware information included the types and relative distribution of personal computers at the proposed installation sites. The data on central processing unit (CPU) power and speed, random access memory (RAM), hard disk size and amount of free space available and multimedia kits is helpful in determining the potential for fleet implementation. The software issues include current and future software performance, documentation and database standards that are in use by the Navy. The results of this portion of the investigation help ensure a smooth transition to fleet implementation. This information will be used to ensure compliance of the proposed device prior to the implementation phase.

The two proposed installation sites were multi-use classrooms with simulated shipboard helicopter control stations (HCS) in one part of the room. The availability of surplus communications and console equipment and volunteer labor were factors in the fidelity of the mock HCS. Currently, students using the rooms may be in the LSE or Helicopter Control Officer (HCO) courses. The type of training includes the Night Vision Goggles orientation and procedural training for Helicopter Control Officers. Slides illustrating helicopters at various stages of the shipboard launch and recovery are projected onto a reflective screen at the front of the room to create the synthetic training environment. LSE hand signals may be demonstrated in the classrooms but there is no training device presently available to support indoor LSE training. The proposed VVAST device can and will support indoor training for both the LSE and HCO students.

One non-multimedia equipped desktop computer (80386 CPU) was available in a nearby office but none were present in the potential installation sites we toured. It was mentioned during the first site visit that the HELSUPPRON THREE staff may be getting newer model computer with a Pentium processor in the near future although the delivery date was unknown.

PROPOSED VVAST INSTALLATION SITE ANALYSIS

HC-3 Spaces at NAS North Island, CA

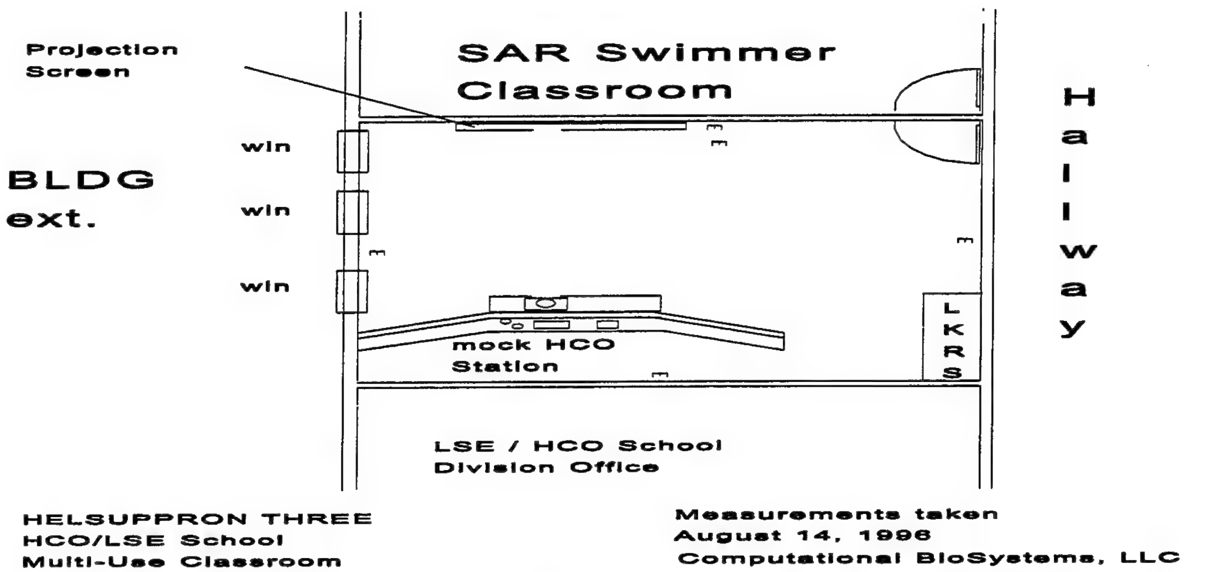
The LSE/HCO school at HELSUPPRON THREE occupies several rooms on the second floor of an older concrete and steel building. The wing commander's office is directly below the multi-purpose room under consideration as the VVAST installation site. Therefore, the noise level generated by the system must be within reason to avoid disturbing the wing commander. This requirement will force a careful evaluation of the sound spectrum produced by the system during the design phases to ensure that low frequency sounds which may travel far in buildings do not reach undesirable levels.

During the site visit to North Island, we were able to inspect one of the proposed sites for the device installation. The HCO/LSE school maintains a classroom modified for student HCO and LSE training. The room is used for both training HCO students in a simulated Primary Flight Control and LSE students in the use of Night Vision Goggles (NVG). In support of the

NVG training, the room walls have been painted a glossy black over the wallboard texture. The classroom is located between the division office and the Search and Rescue (SAR) Swimmer classroom on the second floor of the building. The dimensions of the room are shown in Figure 4.

Figure 4. Proposed installation site at HELSUPPRON THREE's facility.

The drop ceiling height in this room is 8.5 feet. The proposed installation site in the



multi-use room classroom does contain several steel lockers and standard 110 V electrical outlets with metal conduits running exterior to the walls within the room, an eight foot metal pull down projection screen and a metal door frame. Additional metallic objects are located on the simulated HCO training station along the east wall of the multi-use room. The entire motion capture system, cabling and associated peripheral equipment must fit into the spaces shown and allow sufficient room for the trainees, instructors and observers in the final implementation.

HC-8 Spaces at NAS Norfolk, VA

The Atlantic Fleet Helicopter Operations School at HELSUPPRON EIGHT occupies the first floor of an older two story brick and steel building adjacent to the aircraft tow way at NAS Norfolk. The multi-use classroom under consideration as a potential installation site for the VVAST device is used primarily for the HCO course. The simulated tower station is in the back of the room behind three rows of standard classroom metal and wood tables. Various helicopter related equipment such as pendants and flight deck cranials are displayed as teaching aids along the south wall.

The School Duty Office and staff office spaces border the potential installation site. A variety of working communications and lighting equipment has been installed in the mock HCS through volunteer labor. The room is shown in Figure 5. The ceiling is a standard drop ceiling with an 8.5 foot height. The simulated tower is primarily wood in construction with the associated metal and glass components. An instructor's station is tucked into the northeast corner of the room. It is here that the instructor controls the slide display and the various audio communication devices.

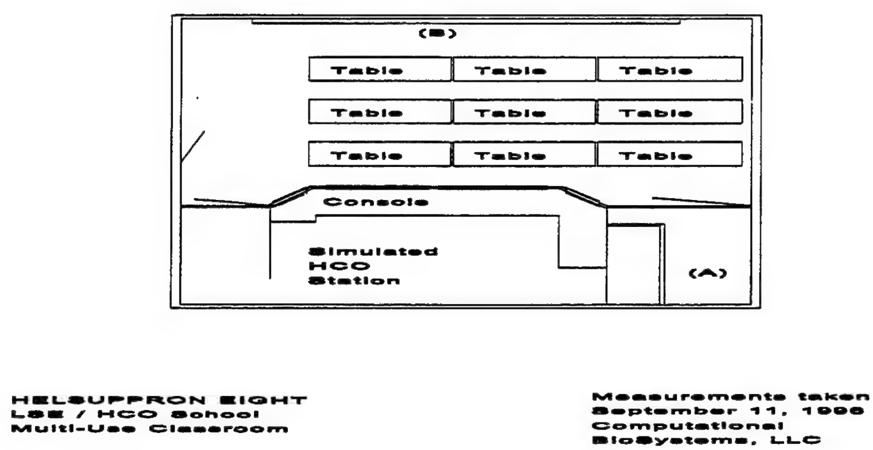


Figure 5. Proposed installation site at HELSUPPRON EIGHT's facility.

The implementation of the VVAST system at this site may require some of the space currently used by the instructor's station. The tradeoff would be the dual capabilities of the VVAST to train both LSE and HCO students in a cost effective manner. This represents a substantial improvement over the use of slides as visual media in that the temporal nature of shipboard helicopter operations could be more closely approximated without the start and stop nature inherent in slide projection.

Evaluation

This objective is considered complete until the prototype VVAST device reaches initial operational capability (IOC) later in this effort. The site inspections revealed that a computer based system would easily fit into the proposed locations and that the limiting factor is the motion capture system footprint. This has been discussed in the second technical objective. As soon as the prototype reaches IOC, the facility inspections will be reevaluated and detailed implementation procedures and costs will be developed.

RELATIONAL DATABASE DEVELOPMENT

The implementation of this device will require an internal database to support full system capabilities. The internal database includes graphical, audio, video, textual and numerical data files to support the various operational requirements. Administrative units may be categorized as system and user support modules. Trainee rosters and performance data may be stored in the Personnel unit. Source materials including the scenario details, helicopter model performance data and hand signal related information comprise the Operational unit. Each module is composed of one or more database tables designed using Boyce-Codd normalization techniques to ensure proper relational operation. The actual location of the database module in the overall program structure is determined by the functional requirements. As procedural and/or platform changes are implemented, the appropriate components of each unit can be upgraded. This approach ensures flexibility and enables the proposed VVAST device to be easily upgradeable.

Administrative Unit

The Administrative unit is divided into system and user support modules. Simulation quality control, NATOPS related administrative information (i.e. change notice implementation dates) and system maintenance information (i.e. up time, problems, etc.) are stored in the system support module. The NATOPS Maintenance database module is where the change notice logs are maintained and is only to be used by supervisory personnel to ensure that the required NATOPS modifications are made and logged in accordance with standard procedure. The user support module includes the user command information such as addresses, standard operating procedures and any other command or agency specific related information. Ideally, it is only accessed at the beginning and end of each session and does not need to remain in memory. This module also provides a means of documenting any problems or software bugs encountered during the device's use.

This module records data on system usage including session start and end times, number of scenarios and signals, instructor modifications to the scenarios, mission success rates (e.g. good vs. bad landing) and related system management information. The agency specific database allows the user's supervisory personnel to specify what signals (whose patterns are already established in the hand signal pattern module) are acceptable for use by agency personnel. In this manner, the device will be more flexible to meet the needs of various government and civilian agencies. The command or agency identification file contains information describing the host command or agency and is primarily used in standard report generation. This can be thought of as letterhead type information.

Personnel Unit

The trainee module captures the identification information for each student and is only accessed at the beginning and end of the session. The trainee's information (e.g. name, rate, SSN and command) may be used during the report generation phase to produce the letter of completion for the trainee's service record. This report could detail exactly what scenarios were practiced in the simulator in addition to current listing the standard PQS watch stations covered by the five day LSE course. This feature would be useful in ongoing training documentation and

can be activated easily if the fleet personnel desire. This module is intended to administratively support the LSE instructor staff by reducing the amount of paperwork that must be processed during the mobile training team schools at remote sites.

Operations Unit

The Operations unit will contain the proper signal progressions for the various launch and recovery phases. The aircraft performance files will include the generic helicopter state parameters and will be expanded to include other aircraft in the future. This module is also extensible for later inclusion of additional aircraft procedural information. NATOPS procedural related information is stored within this unit and linked to the aircraft type. An example of this feature would be the update of the wind limits for a virtual helicopter following release of a new revision of NWP-42 or the aircraft's NFM. In this manner, the system will integrate directly into the standardization system.

In order to reduce the computational overhead, temporary files will be used to store the information and writing the data to the files at the end of each training scenario. The last two database modules are designed for the eventual implementation of this technology in the civilian and foreign military market.

Operational Implementation

It is promising to note that the training syllabus as evidenced by the PQS system may be directly ported to support the operational database management system addressed in technical objective (6). The standard questions listed at the beginning of each section and desired standard answers may be imported into a properly designed data base for use by the simulation. The general nature of the PQS system allows sufficient flexibility that the incorporation of specific helicopter and landing platform information is within grasp. During the Phase I effort, we shall focus on the development of a generic helicopter model which will enable extension to several other fleet models in the Phase II work.

User Interface

The most unappetizing part of computerized record keeping from the user's perspective is typically the interface. The standard graphical user interface (GUI) does offer several advantages to the average user. The design of the interface is not an insignificant task and in order to gather user acceptance must be fairly intuitive. Several guidelines for successful interface design have been developed and are being incorporated into the VVAST prototype. The flow of the data collection screens is most important in determining the intuitive feel of the interface. Simple features such as the ability to move between fields with tab, enter and arrow keys can be very important to many users. Compiled program user interfaces often forced the user to move from field to field in a specified order. The object oriented nature of the graphical user interface allows a recommended order to be programmed as a default but the user is free to navigate between fields as they desire. We are attempting to design the interface to closely follow the format of the available student information.

In order to generate a class roster for students using this device, the data must be entered initially. Three options are available: (1) manual entry for each use; (2) manual entry initially then refer to a roster table or (3) scan in the list and convert the image to database format. The first alternative is clearly labor intensive and will not be pursued further. The second alternative is under development with the concept that a school staff member could enter the class roster into the program at some time before the students use the VVAST device. When the trainee "steps up to the platform," the instructor would simply have to select the student's name from a drop down list by clicking on it. This is an effective means of initializing the identification tables without having to retype data for each user.

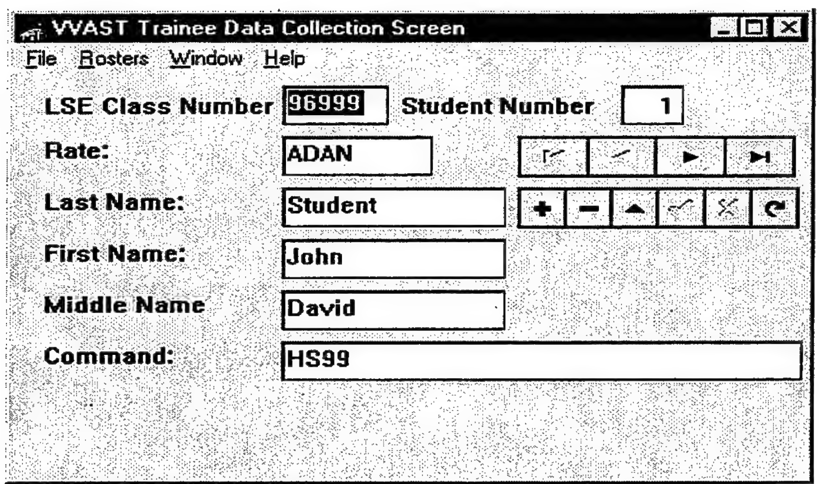


Figure 6. Potential Trainee Data Collection Screen.

Once the trainee's information has been entered into the proposed VVAST system, The instructor can simply select the student's name and training scenario with a few keystrokes or mouse clicks. Figure 7 illustrates a potential scenario initialization page where the instructor is starting a new scenario for a previously entered student.

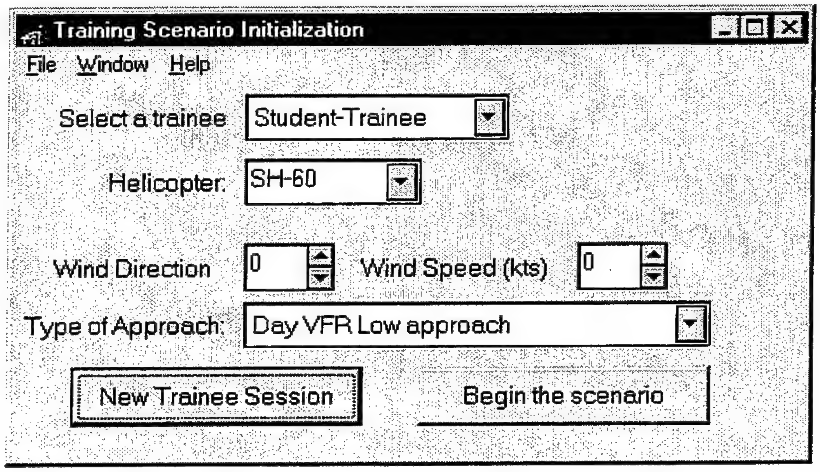


Figure 7. Proposed Training Scenario Initialization Screen

The latter alternative will be explored once the prototype is fully functional. The concept is that an inexpensive portable sheet fed scanner could read a list of formatted and typewritten names and convert this directly to the database format. This is becoming more common in document management as typed case files are being scanned into a word processing file instead of retyping the entire document. The conversion to a database format involves two extra steps, a pre-scan formatting of the data and a conversion routine from the image/word processing format to the database format. The technology is readily available to do this for typed pages. Handwritten data requires the use of advanced optical character recognition (OCR) software. Our initial tests with OCR software on scanned handwritten reports were not encouraging although the typed pages went through cleanly. The availability of inexpensive scanners that feed data into the computer through either a proprietary card or the parallel port makes this alternative attractive for the Phase II effort to reduce data input errors.

Memory storage requirements

The determination of the individual trainee record and annual memory storage requirements is now underway using information gathered during the last site visit. While the final numbers will not be available until the field types and sizes are determined later in the Phase I effort, preliminary estimates are possible using a yearly student throughput of 700 students at each school. It needs to be determined what demographic information (i.e. name, rate, command, SSN, etc.) is truly required by the school and what is "nice to have" type data. As the prototype becomes more defined and possible data structures are known, we intend to contact the two schools for their inputs. Once the feedback is received, then the memory structures and requirements will be determined and implemented.

Report Generation

The sample letters of completion provided by instructors at both LSE schools specifically identify which PQS watch stations the curriculum covered. It is assumed that the course graduate participated in all activities described in this letter. Linking the trainee's performance in the simulator to a relational database system could potentially reduce the amount of administrative overhead required of the instructional staff. As the LSE trainee is provided with the various emergencies, an entry can be made to a file that is later used to report what the student's actual experiences and performance were. This would be done automatically with no input than the instructor's initial data entry and request for the printed report. This is a possible feature to be developed once the prototype is fully functional.

While the potentially explosive growth of possible reports containing student performance data may be technically feasible, the operational usage of the proposed device must be considered. Detailed reports of what signals each trainee gives the pilot during the three pad sessions are not currently maintained due to the logistical support required for such data collection. Furthermore, there doesn't appear to be an administrative requirement for this information at the present time. This capability can be made operational later in the development process should the fleet determine that individual trainee performance data is necessary.

Summary

At the present time, the data structures and relationships have been defined and supported. The analysis of long term data storage is possible based on the available and projected technology in this rapidly changing field. This objective is considered complete until further data analysis and storage requirements are promulgated.

TECHNOLOGY TRANSFER

The work in support of this technical objective has focused on the analysis and development of the market with other federal, civilian and private sector agencies involved in helicopter operations. A preliminary analysis of the pertinent trade associations and related journals is underway for the advertising and marketing of the VVAST device. The analysis of the foreign marketing potential is also underway in view of the number of air capable ships that have been transferred to allied navies in recent years. The potential areas for transfer of this technology may be divided into four areas: (1) related U.S. Navy and defense applications, (2) Federal government agencies, (3) Civilian municipal and private public safety agencies and (4) Foreign military and public safety agencies.

RELATED U.S. NAVY APPLICATIONS

The underlying structure of the proposed VVAST device may be used for several related applications that further the Navy's desire of creating low cost training devices using synthetic environments. In view of the commonality of task components, there are potential uses within the other military services. The task components include the specific hand and arm signals which in many cases have similar meanings in the civilian market. The proposed VAST simulator operates on the acquisition and interpretation of these hand signals to control objects in the virtual world. While a majority of the work and related technology has focused on fine movements, the military movements are coarser and have a greater magnitude. This area has not been explored in any significant detail to date.

The advantage of the synthetic training environment is that different scenarios can be developed and called as needed. This is clearly seen in the ability of the proposed device to change the shipboard landing platform characteristics as desired. The nature of three dimensional computer graphics offers a relatively simple solution to the development of a similar training device for another critical member of the shipboard helicopter operations team. A minor modification to the graphics module can produce a view of the flight deck operation from the Helicopter Control Station. Therefore, the proposed VVAST device provides the Navy with a two for one training device that can promote interaction between the Helicopter Control Officer and the LSE.

Aircraft Handling Aboard Ship

Aviation Boatswain's Mates (Handlers) are charged with the responsibility for safe and proper movement of fixed and rotary wing aircraft aboard ships at sea. They represent a crucial component of flight and hangar deck safety and operational readiness. Aircraft directors (a.k.a. "yellow shirts") and handlers ("blue shirts") are typically junior enlisted personnel whose training is a combination of post boot camp schooling and substantial on the job training. The Personnel Qualification System watch stations involve both academic and practical experience similar to that described earlier for the LSEs. The aircraft directors use hand signals identified in the Aircraft Signals NATOPS Manual to control the actions of the aircraft tractor driver, chock walkers and safety observers.

training is a combination of post boot camp schooling and substantial on the job training. The Personnel Qualification System watch stations involve both academic and practical experience similar to that described earlier for the LSEs. The aircraft directors use hand signals identified in the Aircraft Signals NATOPS Manual to control the actions of the aircraft tractor driver, chock walkers and safety observers.

The only audible warning system used is a whistle signal that may be used by any member of the aircraft movement team who observes a potentially hazardous situation. Chock walkers are aircraft handlers who are assigned to carry tie down chains and wheel chocks while walking alongside the main landing gear wheels. When signaled by either a hand signal from the director or a whistle signal from anyone, the chock walkers are to immediately place the chocks around the wheels to secure the aircraft. While major losses of life and property can occur if a flight/hangar deck aircraft director or handler makes a significant error, minor miscalculations on the order of inches may effectively remove one or more assets from availability for an extended period of time. A small "crunch" can result in extensive repairs depending on where the damage occurs. Supply related delays can add to the repair time for a deployed ship.

The proposed VVAST device may be readily adapted to create a synthetic environment training system for aircraft directors suitable for use at the training school. The hand signals, recognition modules and necessary software to control a virtual display in this type of system are nearly identical to that required to create a similar device for aircraft director (flight and hangar deck) training. The flight and hangar decks are complex environments with many subtle features that are not described in the publications. The real depth of aircraft director training comes from on the job experience which is at times, expensive. The application of the VVAST device technology to this program may provide long term cost savings resulting from more in depth training available to potential aircraft directors.

The movement of aircraft on the flight and hangar decks involves many of the same issues facing the VVAST device in terms of multi-sensory input, movement and perspective estimation and three dimensional deck movement. Computational BioSystems is fortunate to have two personnel with recent flight and hangar deck aircraft handling and training experience. Mr. Norling has served as the Hangar Deck Officer aboard USS ENTERPRISE (CVN-65) and received the Navy Commendation Medal for his development of an aircraft director training program that resulted in over 15,000 aircraft moves without a fire, fuel spill or major incident during an around the world deployment. Mr. Ram is an former Flight Deck and Hangar Deck Aircraft Director whose experience includes tours aboard USS ENTERPRISE (CVN-65) and USS TARAWA (LHA-1). The combined perspectives and experiences make the development of a synthetic environment training device for aircraft director training based on the VVAST system technically and economically possible within a reasonable period of time.

Helicopter Control Officer (HCO) Training

The LSE schools are co-located with the Helicopter Control Officer (HCO) courses and many of the instructors at each site teach both. The two positions work closely together in the fleet. Student Helicopter Control Officers attend a five day training program where they are introduced to many aspects of shipboard helicopter operations. While some may be familiar with

aviation, many are assigned to air capable ships in other capacities. Many of the same topics taught in the LSE school are covered in the HCO class albeit from a slightly different perspective. As we reviewed the Shipboard Aviation Facility Resume to determine which ship platform characteristics to include in the graphics module, it became apparent that a change in the virtual camera angle would present a view strikingly close to that seen from the Helicopter Control Station (HCS).

Three dimensional computer graphics are based on matrices and each point has three coordinates (x, y and z). While the virtual environment is being displayed to the LSE Trainee from one position relative to the origin of the virtual world, a second view can be determined by inserting the coordinates of the HCS in place of the LSE's position. The computer will recalculate the object locations and perspectives and update the display. This is commonly done in flight simulators where the view from a spotter plane is selected. The benefit to the Navy is that the proposed VVAST device may not only present a means of training the LSE students but may be used for the HCO students as well. The concept can even be extended to include the possibility of an integrated training session with the HCO students being able to watch the LSE as he signals the virtual helicopter. There is a tremendous potential for adding to the depth of training for both students as this device reaches the production version.

Other Military Applications

The VVAST device may find ready application and acceptance with other Department of Defense components involved in the use of helicopters aboard ships as a result of the standardization of operating procedures through NATOPS type programs. The potential of this device to support U.S. Coast Guard operations is high in view of the similarities between the ship and aircraft platforms. The other uniformed services may find applications of this system in terms of the capture and automatic interpretation of standard hand signals. The potential uses of this technology may include aviation and non-aviation related applications to replace a portion of live training sessions with synthetic environment training devices. The cost savings associated with the transfer of this technology for these purposes could be substantial.

FEDERAL GOVERNMENT AGENCIES

In order to maximize the applicability of the VVAST device, we have been contacting the various governmental and private agencies who routinely use helicopters. We have been referred to the Air Safety Officers for the National Park Service - Southern Arizona Region and the Tonto National Forest after our initial contacts and met with representatives of those agencies. While some minor differences exist, there is one overall directive that is used as a foundation. The Interagency Helicopter Operations Guide (IHOG) is a federal publication published every three years with the assistance of the National Interagency Fire Center in Boise, Idaho, the U.S. Forest Service and the Department of the Army. This comprehensive manual is used by many governmental agencies in managing helicopter operations including the National Park and Forest Services.

While several chapters are dedicated to the administrative requirements of flight operations with multiple helicopters, there is a section of one chapter that deals specifically with ground signalmen and hand signals. The Incident Command System (ICS) is a fire management system where different units are broken out into operational sectors by task. The Parking Tender

is the ICS equivalent of the military LSE and is responsible for many of the same areas.

Hand Signal Analysis

The actual hand signals specified for use by the IHOG number just sixteen with some substantial differences. The ten signals that are identical or very similar to those listed in the Aircraft Signals NATOPS Manual are Move Up, Move Down, (Hold) Hover, Land Here, Move Forward, Move (Rearward) Back, Move left, Move Right, Shut Off Engine and Wave Off. Minor differences are found in the Clear to Start Engines and Clear to Take Off signals. The former is similar to the Engage Rotors signal. The latter signal does not tuck one arm behind the back as the NATOPS Take Off Signal requires. The Clear to Take Off signal uses both arms to point in the desired direction. While Navy helicopter flight operations are generally toward a departure to the LSE's right side to avoid the superstructure on the ship, the desired departure vector is situation dependent and may be to either side of the Parking Tender. The hand signals used are very similar to the NATOPS signals discussed previously. The directional signal equivalents of the Move Left (Right) use the bend at the elbows style for the moving arm rather than a rigid arm motion.

The Move Tail rotor signal is biomechanically different and yet functionally equivalent to the NATOPS Pedal Turn Left/Right signal. The Move Tail Rotor signal relies more on hip rotation with one arm extended and the other tucked behind the back to indicate the direction of turn desired. The Release Sling Load signal is also different but equivalent to the NATOPS Release Load signal. The Parking Tender's left arm is extended forward and pointed toward the ground while the extended right arm is brought down from over the signalman's head to contact the stationary left forearm. The Hold Helicopter on Ground signal also differs in that the Parking Tender's arms are extended forward and laterally 45 degrees with the thumbs pointed down. There is one firefighting related signal described in the IHOG that has an equivalent in the general aircraft handling signals section of the Aircraft Signals NATOPS Manual. The Open/Closed Fixed Tank Doors signal is nearly identical to the Open and Close Weapons Bay doors signal.

The substantial similarity between the NATOPS and IHOG helicopter hand signals should facilitate the transfer of the VVAST device to other governmental agencies. Since most agencies involved in wild land, range and forest firefighting use the Interagency Helicopter Operations Guide, there is substantial potential for non-military interest and utilization of the VVAST device.

Department of the Interior

The substantial similarity between the NATOPS and IHOG helicopter hand signals should facilitate the transfer of the VVAST device to other governmental agencies. We had been referred to the Air Safety Officers for the National Park Service - Southern Arizona Region and the Tonto National Forest after our initial contacts with those agencies. The National Park Service representative we spoke with was more involved with the actual utilization of fixed and rotary wing aircraft than training. He was kind enough to set up an introduction for us to the Training Manager for the U.S. Department of the Interior's Office of Aircraft Services (OAS). An unexpected benefit to this introduction was that the gentleman's office was located in North Phoenix at Deer Valley Airport. As a quick aside, it was in the later part of the conversation with the Park Service's Air Safety Officer in southern Arizona that we learned he was a Chief Petty Officer (YNC) in the Naval Reserve and was happy to help us out.

A meeting with Mr. Richard A. Johnson of the Office of Aircraft Services occurred on September 27, 1996, at their facility. Mr. Johnson is responsible for providing training to civil service and contract employees involved in aircraft operations for several agencies including the Bureau of Land Management, Bureau of Indian Affairs, National Park Service, Fish and Wildlife Service, Bureau of Reclamation, Minerals Management Service, the U.S. Geological Survey, the Bureau of Mines, the National Biological Survey and the Office of Surface Mining Reclamation and Enforcement. He conducts regular training sessions including the federal equivalent of the LSE school throughout the Western Region. After describing the focus of the Phase I effort and the eventual goal, we had an lively discussion on the similarities and differences between the two types of helicopter operations and training students to use proper hand signals.

In order to advance to more responsible positions in aircraft operations management as described in the IHOG, an individual must amass a number of seasons of practical experience in entry level positions and complete several classes. There is a Basic Aviation Safety orientation that is required of all employees who will be passengers on the government and contract aircraft. The Parking Tenders must complete a 40 hour course (Course number S-217) before being designated. The course includes several practical sessions where the trainees get actual signaling experience with a helicopter. The student contact time may be as much as 15 minutes in a number of different duties including Parking Tender, Loading Supervisor or Safety Observer. Aircraft used for this training can be one of several types and may be agency owned, exclusively contracted or on a call when needed (CWN) contract. Due to the variety of helicopters used by the various agencies and contractors, the aircraft are classified by type and category. Military helicopters may be used by the agencies on an temporary basis and are given a landing area away from the main landing zones due to the substantial rotor blast. The majority of the helicopters used by the agencies are smaller than the military models and as such, rotor blast is not as significant. Parking Tender trainees are advised to adopt a boxer's stance with one foot behind the other much like the LSE's adopt to prevent a loss of balance.

During the field training sessions, some minor hazardous situations are simulated with the permission of the pilot in command (PIC). Example situations include leaving the seat belt hanging outside the door on the side of the helicopter opposite the Tender and leaving a cargo door open to check his observational powers and situational awareness. An additional hazard we

discussed is the potential of the helicopter lifting off with the cargo loading man partially in the aircraft. This is discussed with the Parking Tender students as material transport is a common task in the different agency operations. This scenario is possible in the shipboard operations but is unlikely due to the redundant safety procedures written in NATOPS. However, in each type of operation the LSE/Parking Tender is supposed to point at all personnel approaching the helicopter. The types of flight operations are also similar with external load operations being routine.

The IHOG made several references to changing the magnitude of the signals as the helicopter approaches the ground. Mr. Johnson commented that the hand signals should be given at a consistent, even pace and not be rushed or exaggerated. There is a small philosophical difference in the signalman's role during the takeoff and departure phase. In order to be pilot in command of an agency or contract helicopter, the pilot must have at least 1500 hours of PIC time in his logbook. The general thought seems to be that the pilot is able to lift off all by himself and the additional manpower in the immediate area does not provide any extra safety margin. The program teaches that Parking Tender should get back away from the landing zone once the helicopter has lifted for safety reasons. This may be an option due to the comparatively large landing areas relative to a ship.

Mr. Johnson indicated that his office was starting to look into computerized training and expressed interest in seeing the prototype when it is ready. Two reference manuals were temporarily loaned to us for review and future planning. We are reviewing the S-217 course guide for further similarities. We were also invited to observe one of the Tender classes in the next few months if that would help develop this technology. We intend to follow up on this kind invitation.

Department of Agriculture

We have discussed the VVAST project with representatives of the U.S. Forest Service's Tonto National Forest. A discussion with the fixed wing supervisor in Phoenix yielded some interesting information. Mr. Bob Kuhn of the Tonto National Forest, Phoenix Office, indicated that the refueling and reloading of the slurry bombers is all controlled by hand signals. He stated would be interested in seeing what we come up with as his agency was starting to look at computer based training. The potential inclusion of the hand signals used for the hot refueling and reloading of the slurry bombers is a minor modification of the proposed VVAST system and similar to that discussed earlier for the aircraft director training.

We met with Mr. Gus Tellez and Mr. Don Nunley of the Tonto National Forest at the Payson Ranger Station, Payson, AZ, on November 7, 1996. Mr. Tellez is the Helitack Foreman for the Payson Ranger District and supervises all helicopter training for regular and seasonal employees in the Tonto National Forest. Mr. Nunley is the Helitack Crew Leader and works for Mr. Tellez. The forest area their crew is responsible for comprises mountainous, desert and transitional areas throughout most of east and central Arizona.

The helicopters used in the firefighting and forest management work are smaller and lighter than most military models. They are classified into three categories: Types 1, 2 and 3.

The former category includes the large single or dual rotor helicopters and most military helicopters. Larger helicopters such as the Sky Crane and including most military models are used when available. These models receive special handling at a helibase due to the rotor size and downwash levels. Type 2 helicopters are the medium sized models such as the Bell 204, 205 and 214. The smallest and lightest models are the Type 3 aircraft such as the Bell Jet Ranger (Navy designation TH-57), Eurocopter Models BO-105 and BK 117, McDonnell-Douglas MD-500 series (Army designation OH-6) and several Aerospatiale helicopters (Lama, Alouette III, A-Star and Twin Star). The Type 2 and 3 helicopters are single piloted and most commonly used on the contracts with the Forest Service. Mr. Tellez and Mr. Nunley commented that they seldom, if ever work with dual piloted helicopters and as a result, there is no need to institute procedures to identify which pilot is flying.

The majority of the helicopters are provided on an exclusive use contract basis for extended periods (e.g. 100 days for example). The major types of helicopters used to fulfill the contract requirements within Region 3 (AZ/NM) include the Bell Jet Ranger, Aerospatiale Llama and the Alouette III. In more mountainous or larger regions, medium sized helicopters may be used predominantly. The Forest Service typically operates helicopters in high density altitude situations in mountainous locations. The performance of the helicopter under these conditions is sometimes hard to separate from the helicopter pilot's technique. This is discussed during the training to promote situational awareness.

Crew Training The Helitack crews are made up of two or more senior supervisory personnel and several seasonal employees. The seasonal personnel are a mixture of new hires and returning experienced workers. Therefore, the training needs are somewhat different with the varying experience levels. Initially, all personnel attend the 40 hour S-217 course described in the IHOG and receive additional hands on training with the contract aircraft. A majority of this training is accomplished in the normal course of firefighting work. There is an informal refresher course that may be used with the previously trained returning employees but the practical result is that the crewmembers repeat the S-217 class every season. This enables the entire crew to reflect on past work and more experienced members are able to pass knowledge on to the newer employees.

The Helitack unit personnel are also used to conduct local training with different Hot Shot fire teams located at different regional sites throughout the national forest. The training syllabus is an abbreviated version of the S-217 course that focuses on basic helicopter safety and proper boarding and egress procedures. The Hot Shot teams may use the helicopter for transportation occasionally and an exportable refresher course is prudent. Budgetary constraints have also become an issue for live helicopter training sessions at remote sites.

The most difficult part of the training course was not related to the hand signals but to the load calculations necessary to determine if the helicopter can hover in the ambient weather conditions. This process involves reading the model's performance charts and factoring in the density altitude, gross weight and any wind to identify the weight limits. Students experiencing difficulties with the load calculations receive additional practice sessions and ongoing training.

Hand Signals The hand signals used by USFS personnel are the standard hand signals described in the IHOG. There are some substantial variations in the Move Tail Rotor signal that may originate from pilot preferences or different interpretations of the diagram in the manual. One common variation is to extend both arms forward with the palms together. The signalman then rotates about the hips to indicate which direction the pilot should move the tail rotor. Another variation is to point at the tail rotor and give a modified Move Left/Right signal with the appropriate arm.

Both instructors commented that one difficulty in the training process is teaching the student to account for the time it takes the pilot to stabilize the helicopter's movement. The temporal sequence of the live operation may be a challenge for some trainees to grasp initially. The combined reaction times of the pilot and helicopter to the signals may be longer than that trainee expects. A common problem is to give several signals faster than the helicopter can respond. At higher density altitudes, the helicopter's performance is decreased thereby increasing the response time. During the field training sessions, the pilot is instructed to do whatever the Parking Tender signals within the limits of safe flight. This allows the student to see the effect of not stopping a directional movement. This is emphasized during the external load operations where the signalman must be cognizant of the cargo load's location and movement at all times.

The most common signaling errors involve magnitude and frequency reductions. While the proper signal may involve full arm movement, the improper signal may only involve movement from the elbows. In more extreme cases, the signal may be given by wrist movement only. This degradation has been attributed to complacency, fatigue, a developed familiarity with the pilot's habit patterns and, in some cases, laziness. There is a tendency for this to occur later in the contract pilot's assigned period as the crew's familiarity develops. Contract pilots are typically assigned to a Forest Service unit for varying periods of time such as 100 days. At the end of the assigned shift, a new pilot is brought in and the process repeats itself.

Simulated hazardous /emergency situations The only simulated emergencies that are practiced in the training sessions are related to loading and unloading personnel and equipment from the helicopter. This involves trying to train the Parking Tender to look for open doors, personnel entering or exiting the aircraft or cargo being loaded/unloaded before clearing the helicopter for departure. Although minor hazardous situations such as the seat belt hanging outside the door may be created for training purposes with the pilot in command's approval, this is rare as the helicopters are on contract and the minor cosmetic damage that occurs in this situation is more costly than beneficial to the training process.

Experience Features

The Parking Tenders face many of the same challenges the military LSEs do and have many of the same physical sensations. Signaling a helicopter to land in a confined area under variable wind conditions involves the same thought processes and landing area management as those required for flight deck operations. The minor differences in the actual hand signals do not significantly affect the cognitive issues although the differences in the operational environment (i.e. civilian vs. military) may slightly contribute to a more achievable comfort level with the

evolution.

Visual Sensations The Parking Tenders or "Marshallers" are trained to observe many of the same characteristics that the LSE is trained to watch for. The appearance and sound of the approaching helicopter, the pattern being flown by the pilot and any abnormalities or deviations from the pilot's accepted approach pattern. Additionally, the Marshallers are instructed to carefully watch the movement of any cargo loads suspended below the helicopter. The Forest Service routinely uses long haul lines for external cargo. The load may be anywhere from ten to over one hundred feet below the helicopter. Although the marshallers tend to focus on the models readily available, they can work with any helicopter model at a forest fire helibase. Night helicopter operations do not occur on a routine basis during firefighting or forest management work. Therefore, this is not a major component of the training.

Audible Sensations The marshallers develop an ear for the noise signature. Each aircraft is assigned to a Helitack unit for 100 days and the crew gets very familiar with the helicopter's sound. One of the important comments that was made is that they get very familiar with the sound of the helicopter just before take off. The sound is then used to monitor the progress of the evolution (i.e. "Why is he at takeoff pitch? We haven't cleared him to lift yet."). Both instructors commented that the smaller helicopters do not exhibit blade slap during minor directional movements as many of the larger models do. The noise level is high but reasonably constant.

Tactile Sensations The Helitack crews are taught to be very aware of the direction and speed of the wind produced naturally and by rotor downwash. The IHOG guideline requires the Parking Tender to assume a signaling position with the wind at his back. The Tender is also responsible for providing an accurate estimate of the winds at the Landing Zone. A ten knot difference (e.g. five to fifteen knots) in wind speed can be very critical in high density altitude operations. One commonly used indicator is how much the signalman's pant legs and shirt sleeves are flapping in the wind.

Cognitive The development of situational awareness and a feel for the operational pace are critical parameters to the creation of an expert Parking Tender. The Helitack crew member's daily exposure to the helicopter as both a passenger and a signalman accelerates this growth. Although the crews are civilians and may have little or no military aviation experience, the nature of Helitack work may involve extended periods away from home base similar to the fleet work - up and deployment cycles. The sense of complacency similar to that described by the LSE instructors as "fleet signals" does develop within the crews. The Helitack instructors and supervisors must be vigilant in the same manner that flight deck personnel must be to prevent a mishap.

Related USFS Applications

The use of hand signals in Forest Service aviation operations is not limited to helicopters. The hot refueling and reloading of the slurry bombers is also directed by hand signals. The use of rappelling techniques is becoming an acceptable means of inserting personnel where a landing

is not prudent or possible. The proposed VVAST device can easily be extended to incorporate these training scenarios.

Rappelling In the near future, the Forest Service will be modifying the standard Smoke Jumper insertion techniques from parachuting to rappelling from the helicopter. Mr. Tellez indicated that all Region 3 helicopters will be rappelling capable in 1997. It is important to note that specific hand signals are used both for intra-cockpit and ground to ground communication. The rappelling is controlled within the aircraft by the crewman who acts as the rappel master. A horizontal, outward push type signal is the signal to begin the rappel. It is should be noted that there is no intentional physical contact between the rappel master and those rappelling during this "Start Rappelling Down" signal.

Once the personnel are on the ground safely, the signalman will touch both hands to his head to inform the pilot that everyone is safe on deck. Two emergency signals exist during this evolution. A bad rope (i.e. entangled, etc.) is indicated by the signalman making a slashing motion across the arm much like the IHOG Release Cable signal. The Discontinue Rappel signal is a horizontal slashing motion across the throat. Aside from the Safe on Deck signal, the movements of the ground signalman are equivalent to those used in other aspects of the helicopter operations. Therefore, the extension of the proposed VVAST device to include the rappelling evolutions is straight forward. This provides an additional benefit to the law enforcement community in that the helicopter insertion of emergency response teams can be partially simulated using the proposed device.

Computer Based Training

The proposed VVAST device offers the Helitack crews a method of training the signalmen to anticipate emergencies and handle them appropriately when they do occur. Mr. Nunley related a personal experience with a habit pattern that was significantly modified after a droop stop failure. After the helicopter was on the ground and the pilot was shutting down the engine, it was not uncommon for the crewmembers to exit the aircraft and stow equipment while the rotors were spinning down. A droop stop failure resulted in the rotor disk dropping from overhead to below eye level. The implications of the failure with the normal habit pattern were sufficient to force an immediate modification of the policy. After this incident, the crew rules were changed to prohibit entering or exiting the helicopter until the rotors have stopped completely.

Load Calculations While not directly related to the proposed VVAST device, a moderately complex extension of the generic helicopter model would allow the incorporation of the load calculations as a module. This would be warmly received according to both instructors. In order to realistically model the helicopter's characteristics in the shipboard environment, the generic helicopter model must account for the same performance charts used for the load calculations. The creation of a user interface and validation of the results would not be that substantial as the underlying computational structure is being developed for the VVAST effort.

CIVILIAN MARKET

Helicopters are increasingly used for the protection and safety of the population. Law enforcement agencies, municipal fire departments, government and private air ambulance companies are actively incorporating helicopters into their operations. The number of public safety personnel who have to work around helicopters is much larger than one might expect and includes paid and volunteer personnel. One consistent fact in this arena is that the majority of the training is didactic with the occasional minor live pad session. This is not to be construed in any way that the public safety agencies do not train those personnel who work around the helicopters as well as the military or the previously mentioned federal agencies. The problem is the sheer number of personnel involved. Most will only have occasional involvement with a helicopter during their careers and therefore the costs associated with the multiple live pad training sessions are not economically feasible. The training is primarily lecture and course note oriented for most personnel. The use of volunteer personnel to support and extend the various agency efforts brings in another cadre of personnel who may have limited exposure to the day to day procedures in the public safety agency and even less in the ground operations of helicopters.

Public Safety Agencies

The current state of helicopter operations in the public safety (police, fire department and emergency medical services (EMS) arena is being researched through ongoing personal interviews with helicopter pilots, crew members and administrative personnel from several municipal and rural agencies. The general operating procedures involve a scene condition report that includes a description of the approximate landing zone and nearby hazards such as wires, trees and desired landing instructions (e.g. "Land about 100 feet east of the engine near the patrol car"). In the municipal environment, most landing zones are marked by a strobe light placed in accordance with standard operating procedures. While useful in clearly identifying the desired point of landing, the strobe placement has been a mixed blessing. In at least one incident in the past two years, improper strobe placement at an accident scene resulted in one EMS helicopter being disabled by a wire strike.

While no injuries resulted to the crew or ground personnel from this mishap, it did point out the need for additional resources for landing zone management. Municipal agencies have now instituted a procedure of responding additional supervisory personnel in the form of a fire department battalion chief specifically to monitor the landing area helicopter operations. While on the surface an appropriate response, the implementation of this procedure has resulted minor changes in the field unit behavior. Most EMS helicopter paramedics are part time employees who are employed full time with a larger fire department. In cases where some type of landing zone manager (equivalent to a military LSE) is required, the standard of practice has been to send the part time helicopter medic to supervise the landing if they are not directly involved in patient care and a signalman is needed. The additional supervisory resources (battalion chief or company captain) tend to supervise this individual while the helicopter is on scene. The de facto assumption, which may be supported by some in-service training, is that the individual is more capable signaling to the helicopter by virtue of their off duty employment. This system has generally worked well in a resource rich environment.

When resources are spread too thin to follow this protocol as in high traffic periods or rural areas, the task of landing the helicopter defaults to the on scene law enforcement personnel who typically provide some radio communication on the landing area then simply clear out of the way. In the rural areas, the radio report does not always occur even if the correct frequency for ground contact has been given to the helicopter crew. The EMS pilots we have spoken with have commented that if the initial radio report(s) are garbled, nonsensical or nonexistent, they are more inclined to ignore any subsequent signals from the ground and follow their own best judgement. This includes choosing their own landing site near the scene instead of where the ground personnel have placed the strobe or flashing lights. As one might expect, this has added to the on scene confusion. In many cases, rural agency ground personnel have adopted the somewhat passive attitude that they'll turn on the flashing lights then just let the helicopter do what it wants to. They may resume an active role after the helicopter has landed. The implementation of the proposed VVAST device may substantially reduce this communications breakdown during the critical approach and landing phases by increasing situational awareness and improving signal quality.

The safe operation of the helicopter is clearly the pilot's prerogative. The best course of action any time the situation appears confused is to ignore potentially dangerous signals from excited ground handlers. What is important to the implementation of the VVAST device is an awareness of the fidelity of the simulation and its appropriate nature for training personnel using specific protocols. These protocols may change on a sporadic basis and if the device is adjustable at the end user level to reflect these changes, it will be very well accepted by both pilots and ground crews. Initial responses to the project description have been extremely positive with several pilots and helicopter crew members freely offering anecdotal experiences with good and bad ground personnel signals and the effect on the landing approach.

DPS Air Rescue The Arizona Department of Public Safety (DPS) is the state police agency and operates five Bell 206 Long Ranger helicopters from four permanent bases (Phoenix, Tucson, Flagstaff and Kingman). Each helicopter is staffed by two sworn law enforcement officers, one pilot and one paramedic, and is available seven days a week, twenty four hours a day. The missions of DPS Air Rescue include law enforcement support, search and rescue, emergency medical transportation and other duties as assigned. Air Rescue is an integrated part of the regional EMS network that also contains several private rotary and fixed wing air ambulance services.

As a public agency, DPS is not subject to the same operational limitations that affect commercial air ambulances. Private EMS helicopters are not permitted to use techniques such as the long line (i.e. external load) extraction of a patient while hovering, The DPS helicopter will typically perform the rescue then turn the patient over to a private air or ground ambulance if the patient's condition and circumstances permit. In this way, the Air Rescue crews interact with a wider variety of situations (and ground signalmen) than most EMS helicopter crews.

We met with two DPS pilots, Sergeant Rich Thacher and Officer Jim Knapp of Central Air Rescue on November 11, 1996, at Phoenix Fire Department Station 41 which also serves as the Phoenix Air Rescue base. Sergeant Thacher is the Chief Pilot for the Central Arizona Division and Officer Knapp was the on-duty pilot. Both officers are former Army helicopter

pilots. The discussion focused on two topics: (1) their experiences with the current levels of ground signalman experience and training and (2) what qualities they would like to see developed in the ground signalman. Since Air Rescue acts to support a multitude of agencies throughout the state, they are somewhat logistically limited in providing signal training and must rely on the individual agencies to train their members.

Both officers related several experiences with trained and untrained signalmen present. The latter situation is most common and can include several errors that would be possible but rare in the shipboard helicopter environment. Most errors can directly affect the safety of the helicopter and have resulted in the pilots becoming extra vigilant at all landing zones.

Common Errors

Obstacle Clearance Each new landing zone presents several obstacles to the safe approach and departure of the helicopter. Power lines, trees, street lamps and fences are some of the more common hazards but many others exist such as the surface conditions, small obstructions that may be taller than the skid/wheel height of the helicopter, high "whip" type antennas on vehicles near the landing zone and other helicopters in the immediate area. The type and condition of the surface in the landing area can be a critical issue if the potential exists for the landing gear to become stuck to the surface while the helicopter sits on the ground. This can happen at any ambient temperature depending on the surface type (e.g. cold - ice, snow or mud, warm - mud or asphalt) and may significantly affect the ability of the now heavier loaded helicopter to take off. Any object taller than the landing gear height can be hazardous to the safety of the evolution. Aside from the obvious fuselage puncture hazard, there is the potential for creating a dynamic rollover situation during the critical landing phase. The moment applied by a larger stump or small tree unseen by the pilot and ignored or unseen by the signalman can be sufficient to upset the balance of the descending helicopter and lead to the tipover.

Tail rotor strikes can be a substantial safety hazard due to the reduced visibility at the end opposite of the signalman. The use of composite materials in rotor blades has reduced the flying metal problem in a tail rotor strike. Although the fiberglass shards may not be as dangerous as metal shards, the loss of tail rotor authority can have disastrous consequences to the helicopter and those personnel in the immediate area. "Whip" type antennas are common on emergency vehicles and may present a rotor strike hazard if the vehicle is parked too close to the landing zone. This situation can arise depending on the geography of the scene location, how the drivers parked the vehicles upon arrival and whether the cars/trucks are being used to illuminate the landing area.

The presence of other helicopters in the area of the landing zone creates several areas for concern. The same potential for a mid-air collision exists in their operating environment that exists in any multiple helicopter situation. There is an additional hazard that exists in landing more than one helicopter at an accident scene or even a hospital landing pad. The majority of EMS helicopters are single piloted aircraft. The approach into a confined space landing zone, the size of both the instrument panel and the pilot's size can combine to produce a hazardous situation. If the pilot of the approaching helicopter is unable to see one quadrant of the approach path and continues the approach, a mishap may develop. The approaching helicopter may not

see and therefore strike any hazards on the ground. A recent incident developed along these lines in which the pilot of an EMS helicopter on approach to a Phoenix area hospital did not see a second helicopter sitting on one side of the hospital's landing pad. As the mishap pilot initiated a pedal turn just prior to landing, the tail rotor of his aircraft struck the rotor hub of the helicopter on the ground. Fortunately, there were no injuries and the helicopter landed safely.

Downwash related errors Landing zones may be indicated by strobe lights, flares or be cordoned off with the standard yellow or orange construction type tape. If the signaling devices are not secured, the effect can be distracting at best as the light sources and /or tape is blown away by the rotor downwash. The unrestrained objects can present a foreign object hazard to the helicopter and the immediate area. The rotor downwash can also affect the quality of signals given by a well intentioned but ill-equipped ground signalman. Failure to wear proper personal protective equipment, especially goggles, has resulted in more than one signalman turning away from the helicopter to shield their eyes from the rotor wash. This usually occurs as the helicopter is very close to landing and signalman inputs would be most important (and desirable). Once on the ground, the rotor downwash decreases substantially but signalmen without eye protection may not remain facing the helicopter.

Lookout Doctrine After the helicopter has landed, there is a tendency for some of the ground crews to relax more. Although there may be limited manpower, there may not be anyone other than the aircrew watching the helicopter while the blades are turning. This presents a major safety hazard to the evolution as personnel may approach the helicopter from any angle. There is an additional complication in this medical evacuation situation in view of the different helicopter models used for air ambulances. The height of the tail rotor and the patient loading method vary by model. This has been a source of confusion at numerous mishap scenes where dissimilar models are present. The BK 105 and BK 117 helicopters commonly used for EMS work have an elevated tail rotor and rear patient loading doors. The Aerospatiale A-Star and the Bell 206 load from the side. It is not uncommon for ground crews to become familiar with one model and attempt to follow that training while loading a critically ill patient.

The aircrews must be especially vigilant during the loading process. Severely ill patients are loaded while the rotors are turning in what is called a "hot load" to minimize the on deck time. This technique effectively removes one safety observer (the pilot) from the patient loading process and places the lookout responsibility on the paramedic who is also trying to effectively continue the medical treatment and any available ground personnel. A properly trained ground signalman who is constantly looking for hazards in and around the helicopter would be invaluable at this point. The signalman should be maintaining continuous eye contact with and especially watch areas that are not visible to the pilot.

The transport of a critically ill patient to the hospital adds a sense of urgency to the situation that may lead the signalman to rush the signals to the pilot. Both officers commented that they would really like to see the signalman watching the helicopter carefully before it lifts and throughout the departure process. The process of adding a patient and potentially one more person increases the weight the helicopter must lift and may directly affect the performance of the helicopter. The pilots will begin to lift the helicopter up to a hover by testing for the amount of power necessary to take off with the additional weight. The helicopter will become visibly

light on the skids and may rise to a two foot hover while the pilot ensures that he is clear of the ground. The signalman should be looking for this movement and modulate the signals accordingly.

The sense of urgency may cause the signaler to have signaled the departure before the pilot has completed the hover check. This is not uncommon with inexperienced signalman. If the ground contact gets far ahead of the pilot, they may not be doing any type of visual search of the surrounding area and the helicopter's departure path. The availability of news media helicopters and the "popularity" of mishap scene footage may place several helicopters in inappropriate areas as the EMS ship is departing for the hospital. The development of situational awareness in the non-aviation oriented ground personnel is a critical issue to improving the overall evolution safety.

Light Discipline Although the emergency vehicle lights are helpful in locating the site, the use of lights at an accident scene landing zone can be a double edged sword. Helpful individuals may shine their lights at the approaching helicopter or the signalman may stand in front of bright lights. The implementation of night vision goggles (NVGs) as a standard equipment for night time missions is further affected by the inappropriate use of bright light. In addition to overwhelming the NVG displays, there may be problems with the use of low intensity chemical luminescence devices (i.e. "chemsticks") to mark the boundaries or the landing area to give hand signals. The chemsticks are available in several colors (e.g. red, yellow, green, blue) and are commonly used in the military and civilian environments. The ANVIS 6 systems have component filter that blocks out blue light. If the ground crews are using blue chemsticks to mark the landing area or to give signals, a pilot wearing NVG equipment with the blue filter will not be able to see the light sources. This should be incorporated in the training syllabus for ground signalmen to help develop the situational awareness during night operations.

Ground Signalman Training The training program for ground signalman is the primary responsibility of the various agencies that the DPS Air Rescue supports. The crews do provide a general aircraft orientation that includes the proper boarding and egress procedures. Although there is a strong need and desire to improve the quality of landing zone procedures, there is little formalized training available due to budgetary and logistical concerns.

Desired Situational Awareness Qualities There are several areas that the officers felt would be great to train the potential ground signalmen in to help them develop situational awareness. Many of the comments were identical to those made by LSE instructors during the fleet personnel interviews. Are the signalmen following the progress of the evolution? Are they paying attention to what the helicopter is doing? Are they anticipating emergency situations (i.e. fires, crashes, mid-air collisions) before, during or after the helicopter is on the scene? Do they understand what is involved in the dynamics of a heavily loaded, hovering helicopter? Do they understand how and when to issue a Wave Off? Do they understand tail rotor hazards? Does the ground signalman have control of the landing area? Do they increase the safety parameters at night and try not to rush at night? Are the ground personnel wearing proper personal protective equipment?

Several more comments were more relevant to the civilian EMS market. Are the ground

contact personnel on the same frequency as the approaching helicopter? Have they really looked around for power lines and other flight hazards that may be invisible to the pilot at night? Is the landing zone clearly marked and are the markers properly secured? Are the ground personnel practicing appropriate light discipline to not endanger the helicopter? If they do not have a ground signalman available to meet the helicopter, are they at least giving some type of landing zone information over the radio?

The use of lighter helicopters in the EMS roles (i.e. the IHOG classifies them as Type 3 helicopters) makes the signalman's awareness of the individual helicopter's hover performance even more critical. The sudden addition of a 200 lb patient load is more of a significant percentage of the useful weight than in a larger and more powerful Type 1 helicopter such as the SH-60. The proposed VVAST device can provide a means of training the civilian ground signalmen in several of the areas addressed by the two Air Rescue pilots.

Search and Rescue

The National Association for Search and Rescue (NASAR) estimates that nearly 90 percent of the search and rescue (SAR) teams in the United States are composed almost entirely of volunteers. These personnel maintain full time employment in other occupations and respond to emergency situations when called out. The advantages of a helicopter in rapidly searching an area for a missing hiker or inserting a SAR team in the area of an injured hiker are a very compelling argument for the use of rotary wing aircraft. While the time and transportation issues are important, the critical phase of the entire operation is as the helicopter approaches, lands and takes off from an unprepared site in the wilderness to support the operation. These landing zones (LZ) may be in a flat clearing or meadow or on a small flat spot on a ridge line. Alternate landing spots may also include hillside, canyon or pinnacle LZs.

Each site has its own set of problems that the SAR LSE/Parking Tender must be aware of. The challenge to each SAR team is to train and provide competent signalmen to every call where a helicopter is involved. This usually defaults to three or four highly motivated volunteers who attempt to gain experience in helicopter operations through reading and observations at the occasional public safety agency practice session. Mostly, this becomes an academic exercise through reading handouts and lecture notes photocopied from supportive agency employees. Operationally, this results in a situation where a SAR team will get the reputation of having one or two good helicopter people whose absence may be noticed by pilots familiar with the team.

SAR pilots have been known to alter their mission planning significantly if no competent ground contact is available on scene. This can result in one of two situations. The pilot may attempt to supervise the ground operations by radio as he's flying in or he may not be as willing to take a chance on a landing zone close to the scene. The more common and prudent situation is to reduce the helicopter's involvement to avoid flying into a hazardous situation. In the former case, the helicopter pilot may take unnecessary chances due to the real or perceived urgency or to showcase a "can do" attitude and skill level. We are personally familiar with one incident where a pilot made a landing on top of a thirty foot pinnacle to drop off a SAR team near the location of a known deceased hiker "to save time." The ground team that left five minutes before the helicopter took off arrived on scene at the same time as the team flown to the pinnacle LZ. In

view of the known fatality, the additional risks taken by the helicopter pilot to reach the hillside location were unwarranted yet the "can do" attitude prevailed during the mission planning. In the latter case, the SAR pilots may choose a landing zone farther away from the scene that they are comfortable with and rely on the ground teams to make the final approach on foot. This is clearly the more prudent approach but both scenarios occur commonly and are a function of pilot skill level, weather conditions, perception of the ground SAR team capabilities and perception of the ground team's helicopter knowledge and experience.

The potential for improving and standardizing the quality of helicopter signaling techniques and base knowledge with the VVAST device is substantial. Wilderness search and rescue teams face many of the same obstacles that the LSE faces in terms of confined space flight deck/landing zone management and overall safety direction. Unauthorized personnel, equipment and even animals can foul the landing area at any time and the ground signalman must be vigilant. Multiple helicopter operations are common on newsworthy or extended search and rescue missions and clearing the departure path before signaling the take off is critical as the news media helicopters may fly irregular patterns searching for the most dramatic video. In eight years of personal volunteer mountain rescue work, I have seen this situation occur numerous times.

The benefits of the proposed device in the SAR community also include a means of conducting and documenting regular helicopter signaling training. In order to maintain team skills at a sufficiently high level, regular training sessions are conducted. The frequency of helicopter training is fairly low unless three conditions are satisfied. There must be a supportive (and usually sponsoring) public safety agency that operates one or more helicopters in the team's area. There must be a cadre of motivated SAR team members who are dedicated to safe helicopter operations. Lastly, the team's typical mission profiles must include sufficiently routine helicopter usage to warrant the sponsoring agency's participation in training the volunteers. This last condition can be affected by interagency politics and perceptions of untrained personnel and is also the most difficult to satisfy. The use of the VVAST device to train the ground team personnel in standard hand signals would go a long way toward improving helicopter safety at wilderness SAR bases especially in the volunteer area.

The advent of long line rescue techniques in the SAR arena has forced additional responsibilities on the ground signalman. Long line techniques are a variation of the military personnel insertion / extraction methods in which personnel and equipment are suspended below the helicopter by a low stretch nylon rope. In the SAR application, an injured hiker is extracted from a rough area by this technique. In many cases, a paramedic will ride along with the victim who is strapped in a Stokes litter. A key point to remember here is that most of the public safety helicopters are lighter and less powerful than the military aircraft (i.e. compare a Bell 206 Jet Ranger and a CH-46 in terms of size and lifting capacity). Therefore, these helicopters may operating closer to the edge of the safe envelopes for the same load conditions than the comparable military helicopter. While this is clearly the pilot's safety of flight decision, the envelope gets pushed quite a bit because of expediency, convenience or other non-aviation related reasons.

The ground signalman's functions in the long line operations are increased as he or she

must properly position the lines so that no obstructions are encountered during the take off and departure phases. The noise level at the landing zone effectively prevents radio communication and hand signals must be used. The management of the 150 foot ropes hanging below the helicopter is critical to the safety of flight and weights are required to prevent the ropes from blowing up and fouling the rotors. The VVAST device could easily be modified to present this scenario to the ground signalman trainee. It should be noted that more and more fire departments and other public safety agencies are entering the long line wilderness rescue world with designated certificate level courses being offered regularly in rope rescue. The content of these courses is somewhat standardized and graduates may tend to use the long line rescue techniques frequently if there is a helicopter available even with a patient with minor injuries. This trend should continue for the foreseeable future.

FOREIGN MARKETS

Helicopters are an integral part of the American landscape with the multitude of applications discussed above. They are an important part of the system in developing countries as public utilities such as electrical power, water and communications infrastructures are built. The hand signals used for ground to pilot communication are identical or similar to those listed in the International Civil Aeronautics Organization (ICAO) manuals. Therefore, a market exists for the proposed VVAST device to assist the allied nations in improving the safety of helicopter operations. The underlying structure of the simulator is language independent and only the user interface will need to be customized to the native language of the host country. This is not a major technical challenge and can be readily installed.

It is necessary to ensure compliance with the current export laws, policies and regulations as restrictions do exist on what types of advanced software can be exported to countries other than the United States and Canada. When the device development is approaching this stage, we will ensure compliance as required before opening up the international market. This will also take a substantial amount of research to learn the proper way to market the device overseas.

SUMMARY AND FUTURE DEVELOPMENT

There is clearly a market for this technology with federal, municipal and private helicopter agencies. The modular construction of the VVAST device will enable the rapid transfer of this technology to the other markets. Different hand signal profiles and protocols may be included to work with relevant training scenarios to further the device's implementation. This technical objective is considered complete. Further market development will occur after the prototype reaches initial operational capability. We have identified several trade shows and related events to further market the product.

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